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Studies on the zeolites. Part V. Mesolite.[1]

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Mesolite was first recognized as a separate species by J. N. Fuchs (1816), being one of the three species into which he subdivided R. J. Haüy's species mesotype (1801). Its individuality has been repeatedly doubted, many workers regarding the mesotype group as an isomorphous series with natrolite and scolecite as the end-members, and mesolite merely an intermediate isomorphous mixture. The frequent occurrence of intergrowths of mesolite with natrolite or scolecite is largely responsible for this confusion, these intergrowths frequently passing for single minerals, and being adduced as evidence of the occurrence of all intermediate compositions in the supposed isomorphous series. Faroelites, and mixtures containing faroelite, have also been analysed as mesolite from time to time.

Doubts as to the individuality of mesolite have persisted even after the work of R. Görgey (1908, 1909) and H. L. Bowman (1909), but the present work provides strong evidence of the correctness of their conclusions: natrolite, mesolite, and scolecite are three distinct and separate species, isostructural, but not isomorphous, differing in symmetry, and with a limited degree of isomorphous replacement.

[1] Part IV. Ashcroftine (kalithomsonite of S. G. Gordon). Min. Mag., 1933, vol. 23, p. 305.

With such confusion over the status of mesolite itself, it is not remarkable that there has been much confusion over its varieties. *Poonahlite* was described by H. J. Brooke (1831) from Poonah, Bombay, India, and there has been considerable confusion as to its proper place. Many authors have classed it with scolecite, but H. L. Bowman (1909), who deals fully with its history, proved its identity with mesolite. *Harringtonite* of T. Thomson (1836) has been widely regarded as mesolite, but in the author's opinion [1] it was really a compact and intimate mixture of thomsonite and mesolite.

Another of T. Thomson's County Antrim minerals, *Antrimolite* (1836), has also been assumed to be mesolite. Thomson's original analysis is quite uninterpretable, while one by W. Parry made in R. D. Thomson's laboratory (1846) would appear to be a mesolite, as were two specimens analysed by M. F. Heddle (1857). But an examination of several specimens in the British Museum, obtained between 1837 and 1850, and including some purchased from the dealer (P. Doran) who supplied Thomson, suggests that appearance was the main factor in the classification of this material; antrimolite probably consisted simply of any fibrous zeolite or mixture of zeolites, coating scalenohedra (generally amber-coloured) of calcite, and so attaining somewhat of a stalactitic appearance. Mesolite, scolecite, natrolite, thomsonite, and mixtures of these have all been found as such specimens, and unless Thomson's original material can be re-examined, there is no evidence that any of these has a better right to the name of antrimolite than any other. *Verrucite* of J. Apjohn (1845), also from Co. Antrim, is shown by his analysis to be simply mesolite.

Pseudomesolite of A. N. Winchell (1900) cannot be united with mesolite if Winchell's results are correct, for it would appear to be monoclinic, fibrous, and elongated perpendicular to the symmetry-axis, with probably the same optic orientation as scolecite, but very low birefringence, optically positive, and a composition nearly identical with that of mesolite. The species certainly calls for further examination by modern methods. The optical properties of O. Luedecke's 'mesolite' from Pflasterkaute, Eisenach (1881), suggest pseudomesolite; but his analysis was probably made on a mixture. E. Rimann [2] has also examined material, the optical properties of which suggest pseudomesolite; a re-examination of either of these specimens would be of considerable interest.

[1] Part II of this series, Min. Mag., 1932, vol. 23, p. 113.
[2] E. Rimann, Centr. Min., 1909, p. 767.

Metamesolite of A. Cavinato (1927) is merely dehydrated or nearly dehydrated mesolite, and, as will be shown below, has no claim to species rank.

The material examined under the name of mesolite by E. Hussak[1] differs notably from mesolite in composition, cleavage, and optical properties, and may be a distinct species. It would undoubtedly repay re-examination.

Chemical composition.

Five new analyses of mesolite were made on carefully selected and optically tested material, with the results shown in table I. These specimens were used for all the other work described below.

TABLE I. New chemical analyses of mesolite.

		1.	2.	3.	4.	5.
Percentage Composition.	SiO_2	46·05	47·13	46·98	46·15	46·1
	Al_2O_3	26·84	26·02	26·43	27·04	26·6
	CaO	10·00	10·09	10·06*	9·73	10·6
	Na_2O	3·82	4·50	4·57	4·64	5·1
	K_2O	0·79	0·11	0·05	0·06	—
	H_2O	12·30	12·17	11·94	12·36	12·0
	Total	99·80	100·02	100·03	99·98	100·4
	Oxygen %	41·21	41·40	41·53	41·30	41·3
	Oxygen, atoms per unit cell.	240·5	241·7	242·6	240·8	241·1
Atoms per 240 oxygen.	Si	70·9	72·2	72·8	70·8	71·1
	Al	49·8	47·9	48·3	48·8	48·6
	Ca	16·9	16·9	16·7	16·3	17·4
	Na	11·6	13·6	13·7	14·1	15·3
	K	1·6	0·2	0·1	0·1	—
	H_2O	64·5	63·3	61·8	64·5	61·5
	Si+Al	120·7	120·1	121·1	119·6	119·7
	Ca+Na+K	30·1	30·7	30·5	30·5	32·7
	Sp. gr. (D_4^{19})†	2·258	2·258	2·258	2·256	2·257
	Refractive index (β)	1·507	1·507	1·5074	1·507	1·507

* SrO tested for and found absent. † Corrected to vacuum.

1. B.M. 33868. Bhore Ghaut, Syhadree Mts. (= Siahadri Mts. or Western Ghats), Bombay, India. Dull crystals.
2. B.M. 31746. Iceland. Radiating, coarsely prismatic.
3. B.M. 49969. Syhadree Mts., Bombay, India. Clear large crystals.
4. B.M. 95279. Kvivig (= Qvivig), Strömö, Faeroe Islands. Clear crystals.
5. B.M. 1914,754. Burger's quarry, West Paterson, New Jersey, U.S.A. Long thin needles.

[1] E. Hussak, Bol. Comm. Geog. Geol. Estado São Paulo, 1890, no. 7, p. 244; abstract in Zeits. Kryst. Min., 1892, vol. 21, p. 405.

As mentioned above, a number of the older analyses of 'mesolites' were undoubtedly made on impure material mixed with natrolite, scolecite, or faroelite, and these must be rejected in considering the composition of mesolite. There is no satisfactory criterion to ensure their rejection but optical study, and this unfortunately involves rejection of most of the analyses hitherto published. In only seven analyses from the literature is an optical control of the purity of the material mentioned.

It was at first supposed, on the strength of the remarkable similarity between X-ray rotation photographs of natrolite, mesolite, and scolecite about the axis of elongation of the crystals, that the unit cell of mesolite must contain 80 oxygen atoms. It therefore seemed that the correct unit cell formula must be $Na_4Ca_6Al_{16}Si_{24}O_{80}.22H_2O$ with, normally, a small replacement of Ca by 2Na, rather than the formula $Ca_2Na_2Al_6Si_9O_{30}.8H_2O$, proposed by R. Görgey (1908, 1909) and accepted by H. L. Bowman (1909), T. L. Walker and A. L. Parsons (1922), A. N. Winchell (1925), and A. Cavinato (1926, 1927). But it seemed curious that the atomic proportions calculated from the five new analyses and the seven selected analyses from the literature should be in better agreement with Görgey's formula than with the new one.

Further work showed that the true unit cell of mesolite contains 240 oxygen atoms, one of the cell-sides (*a*) having approximately treble the length of the corresponding cell-side (*b*) of natrolite. Görgey's formula is therefore correct and represents one-eighth of the unit cell contents, the true unit cell formula being $Ca_{16}Na_{16}Al_{48}Si_{72}O_{240}.64H_2O$. The atomic cell-contents, calculated from the densities, analyses, and cell-sides are given for the five new analyses in table I, and for the analyses from the literature in table II. There is often a small replacement of Na by K (up to 1·6 atoms per unit cell), and there is commonly a small replacement of 2Na by Ca, rarely the reverse. The Si/Al ratio does not seem to depart notably from 1·5; any small departure is usually by way of excess alumina, but there is no evidence suggestive of $NaSi \rightleftharpoons CaAl$ substitution. The water content is perhaps open to some doubt. The five new analyses agree in suggesting $64H_2O$, but many of the analyses from the literature lead to higher figures, 68 or $72H_2O$ per unit cell.[1] The study of the

[1] The space-group, C_2^3 (face-centred aspect), indicates that the water content must be a multiple of 4 mols. per unit cell, and the very close approximation to the orthorhombic space-group C_{2v}^{19} suggests that the water content is most probably a multiple of 16 mols. per unit cell.

vapour-pressure (see below) tends to confirm the figure $64H_2O$, and it is probable that many of the higher values are due to the use of finely fibrous material, to water absorbed owing to fine grinding, or to deliberate saturation by standing over water. The vapour-pressure work on mesolite and on natrolite[1] indicates that such saturation is not justified with these zeolites, complete hydration only requiring a considerably lower vapour-pressure than that of water.

TABLE II. Analyses of optically-tested mesolite, from the literature. Re-calculated in atomic proportions per 240 oxygen atoms.

	a.	*b.*	*c.*	*d.*	*e.*	*f.*	*g.*
Si	70·8	71·8	71·5	72·1	71·6	71·4	71·8
Al	48·9	49·0	48·9	48·1	48·2	48·0	50·2
Ca	18·8	16·5	16·5	15·5	16·2	16·0	15·1
Na	12·5	12·7	14·0	15·9	16·0	18·5	11·1
K	—	—	0·4	0·2	0·8	—	—
H_2O...	69·3	69·0	65·7	64·5	64·8	67·8	85·5
Si+Al	119·7	120·8	120·4	120·2	119·8	119·4	122·0
Ca+Na+K ...	31·3	29·2	30·9	31·6	33·0	34·5	26·2
Class of analysis ...	A	B	A	A	A	B	C
Sp. gr.	—	—	2·260	2·26–2·27	2·257	2·272	2·18

a. A. Cavinato, 1926. Iceland.

b. A. Cavinato, 1927. Berufjord, Iceland.

c. T. L. Walker and A. L. Parsons (E. W. Todd, analyst), 1922. Cape d'Or, Cumberland Co., Nova Scotia.

d. H. L. Bowman, 1908. Poonah, Bombay, India. Var. poonahlite.

e. T. L. Walker and A. L. Parsons (E. W. Todd, analyst), 1922. Gates mountain, Annapolis Co., Nova Scotia.

f. R. Görgey (E. Ludwig, analyst), 1909. Faeroe Islands.

g. E. E. Schmid, 1871 and 1880. Iceland. Optically examined by O. Luedecke, 1881.

Only those analyses for which optical tests of the purity of the material are mentioned are included in table II (where they are classified as was done for thomsonite), but the majority (38) of the remaining analyses are in good agreement with the new formula, and it seems reasonable to explain the others (10) as analyses of mixtures.[2]

[1] Part III of this series, Min. Mag., 1932, vol. 23, p. 243.

[2] In all, 64 analyses were collected from the literature, of which 18 were accounted as first-class, 15 second-class, 22 third-class, and 9 rejected as worthless. Potash was estimated or shown to be absent in only 5 of the first-class, 3 second-class, and 3 third-class analyses. The method of classification, as was explained in Part II of this series, cannot detect admixture with another zeolite. No method yet proposed for the evaluation of analyses would.

Crystallography, density, and pyroelectricity.

Owing to the confusion of the three members of the mesotype group, and the invariable occurrence of mesolite as supplementary twins, the latter was long regarded as orthorhombic. Optical studies by several workers have shown that mesolite crystals are invariably twinned, but there is a conflict of evidence as to the true symmetry of the mineral, some classing it as anorthic, others as monoclinic. The author's optical studies, and X-ray work by F. A. Bannister, point to monoclinic symmetry.

The habit of mesolite is very simple, long prisms $r(301)$ and $R(\bar{3}01)$ with a pyramid[1] $o(311)$ and $p(\bar{3}11)$ or $O(3\bar{1}1)$ and $P(\bar{3}\bar{1}1)$ being almost invariably the sole forms observed. The orientation used is based on that of G. Cesàro (1909), modified in accordance with the X-ray results, and depends on optical study. In each individual of the twin, that pair of prism-faces which show a blue colour between crossed nicols are taken as $r(301)$ and $r'(\bar{3}0\bar{1})$; the neighbour to $r(301)$ across the acute normal-angle of the prisms is taken as $R(\bar{3}01)$, whereby the free end of the crystal, carrying the pyramids, may fall either to the right (positive end of the b-axis), or to the left (negative end of the b-axis), which two kinds of crystal may be termed right- and left-handed respectively. This is in accord with the symmetry-class, digonal polar (C_2). The crystals are invariably twinned, consisting of right- and left-handed sectors, as revealed optically, of which either may predominate; or the right-handed sectors may predominate at one end, and the left-handed at the other end of the same crystal. There is no external indication of the twin structure revealed by optical work. The crystals are, indeed, pseudo-orthorhombic, and have commonly been set up with the elongation as c-axis, the prism being indexed $m(110)$ and the pyramid $o(111)$; the above orientation is in better accord with the true axial ratio, as shown by X-ray work, and with the symmetry, and will be used here. The old c-axis becomes the new b-axis, and the old b-axis the new a-axis. The transformation determinant is 030/001/100.

Mesolite crystals from four of the analysed specimens have been measured, but unfortunately only one specimen yielded crystals with

[1] In a previous paper (Min. Mag., 1933, vol. 23, p. 367), the pyramid was given indices of the type (111), in the belief that the cell-dimensions of mesolite were very nearly the same as those of natrolite; further X-ray work has shown that this supposition was incorrect. The a- and c-axes of the present setting were interchanged in the former setting.

pyramid faces that reflect well. The angle rR (301) : ($\bar{3}$01), measured on natural and on cleavage prisms, gave a mean value of 88° 33′, the measurements ranging from 88° 28′ to 88° 40′. The other results are given in table III. The crystals show a rather irregular development of the pyramid, one face being often much larger than the others. The faces of the pyramid were replaced by an oscillating vicinal combination of two faces in the zone [011], (or [01$\bar{1}$]), resulting in striations parallel to this zone, as found by R. Görgey (1909).

TABLE III. Goniometric measurements on mesolite (specimen no. 3).

Interzonal angles:	Crystal 1.	Crystal 2.	Crystal 3.	Crystal 4.	Calc.
$[rR]:[op]=[010]:[01\bar{1}]$	70° 26′	70° 28′	70° 29′	70° 23′	70° 26′
$[rR]:[o'\,p']=[010]:[011]$	70° 28′	70° 33′	70° 6′ (?)	70° 15′	70° 26′
Interfacial angles:					
ro(301) : (311) (vicinal) *	63° 36′ to 64° 3′	63° 56′ to 65° 29′ to 63° 57′ to 65° 31′ to 64° 26′	63° 39′ to 64° 16′	64° 2′ to 64° 42′	63° 36′
$Rp(\bar{3}01)$: ($\bar{3}$11) (vicinal) *	64° 53′ to 66° 7′ to 63° 25′ to 64° 6′	64° 7′ to 65° 1′ to 63° 42′ to 65° 51′	—	63° 40′ and 64° 22′	63° 36′

* Each face o(311) or p($\bar{3}$11) is in general replaced by a pair of vicinal faces in the zone op[01$\bar{1}$]. The replacement is oscillatory, and on the goniometer the signal-image is spread out into a band, brightest at its two ends; the cited angles are for the ends of this band.

If the zones containing the vicinal pyramids be taken as the true [011] and [01$\bar{1}$], which seems *a priori* reasonable, since the interzonal angle [010] : [011] between them and the prism-zone is nearly the same for all recorded measurements,[1] the axial ratio may be calculated from this interzonal angle (70° 26′) and the cleavage angle rR (88° 33′), provided the interaxial angle, β, is known. The latter cannot be obtained from the goniometric data, except that it must be very near 90° as the crystals are so markedly pseudo-orthorhombic; the X-ray work indicated a value for β of 90° 0′ $\pm$ 20′. Taking this figure, the axial ratio computed from the goniometric data is $a:b:c$ = 8·658 : 1 : 2·813, for Cesàro's setting, compared with a ratio 8·640 : 1 : 2·811 from the X-ray measurements. In Dana's setting (c-axis = elongation, a-axis bisects the acute normal-angle of the prism, pyramid = (111)), these ratios become 0·9750 : 1 : 0·3465 (goniometric) and

[1] See W. Phillips (1823), O. Luedecke (1881), R. Görgey (1909), and A. Cavinato (1926).

0·976 : 1 : 0·347 (X-ray). The goniometric value is probably the better.

Five new determinations of the specific gravity of mesolite (see table I) show no appreciable differences; and they are confirmed by the most reliable of the older values. After allowing for the changes in specific gravity and in cell-size due to the potash content (compare natrolite, Part III of this series, loc. cit.), the specific gravity of fully hydrated potash-free mesolite of ideal composition may safely be taken as D_4^{19} 2·256, corrected to vacuum.[1]

Mesolite has been examined for pyroelectricity by several workers, but some of the earlier work is useless owing to uncertainty as to which member of the mesotype group was really used. Positive results were obtained by J. N. Fuchs (1816), Sir David Brewster (1821), and A. Des Cloizeaux (1862), and negative by P. Riess and G. Rose (1843).

An application of the liquid-air method of testing to several twinned crystals from the specimen B.M. 49969 showed that there is a small but definite pyroelectric effect, the elongation (*b*-axis) being the polar axis. The experiments were carried by Dr. W. A. Wooster of Cambridge, whom we wish to thank for his kind assistance in this matter.

No piezoelectric tests on mesolite have been published, though it is possible that the negative result recorded for scolecite by G. Greenwood and D. Tomboulian[2] may be due to the use of mesolite, the two minerals being often confused.

Parallel growths of mesolite and natrolite have been recorded from various localities by several workers.[3] The author has observed mesolite tipping or in extension of natrolite needles from Neubauerberg, Böhmisch-Leipa (fully described in Part III of this series, loc. cit., p. 254) and precisely similar material (save in the length of the needles) from Neuschloss, Böhmisch-Leipa, and from the Dulce quarry,

[1] The specific gravities cited in Parts II, III, and IV of the series are all compared to water at 4° C., but are not corrected to vacuum. The correction may be made by subtracting 0·001 throughout.

[2] G. Greenwood and D. Tomboulian, Zeits. Krist., 1932, vol. 81, p. 30. [M.A. 5–131.]

[3] Mindelberg, Aussig, Bohemia, G. Cesàro, 1909; Friedrichsthal, Bensen, Böhmisch-Leipa, R. Görgey, 1909; Neubauerberg, Böhmisch-Leipa, A. Scheit, 1911; Kara-dagh, Crimea, Miss O. A. Brinken, 1914; Fichtenberg, Salesl, Bohemia, J. E. Hibsch, 1917; Weilberg, Siebengebirge, Rhine, R. Brauns, 1922. Some of these authors have not recognized the mesolite as such.

Marienberg, Aussig, Bohemia. He has also observed mesolite intimately intergrown with scolecite, from Co. Antrim (so-called antrimolite), and from Arendal, Norway; with natrolite, from Richmond, Melbourne, Australia, from Killyflugh and other places in Co. Antrim, and from Talisker, Skye; and with thomsonite from Co. Antrim (so-called antrimolite), from Nordtunga, Iceland, and from the Faeroe Islands. Such admixtures have been described from several other localities, in particular by O. B. Bøggild (1922).

In the course of a re-classification of the fibrous zeolites in the British Museum collection mesolite has been recognized on specimens from several localities which appear to be new for this mineral, at least no mention of them could be found in a survey of the literature; the localities are: Arendal, Norway; Monte Somma, Vesuvius, Italy; Mezzavalle, Predazzo, Fleimsthal, Tyrol; Richmond, Melbourne, Australia; Disko Island, Greenland; Eide, Österö, Faeroe Islands; Tjörnevig, Strömö, Faeroe Islands; and Dulce quarry, Marienberg, Aussig, Bohemia.[1]

X-ray work.

Apart from a Lauegram published by A. Cavinato (1926) as evidence of monoclinic symmetry, the only X-ray work on mesolite appears to be that of W. H. Taylor, C. A. Meek, and W. W. Jackson (1933), who found that short-exposure rotation photographs of mesolite and natrolite are practically identical, and concluded that the two species are isostructural.

Using very thin needles and giving a fairly long exposure, Mr. F. A. Bannister has been able to find very definite differences between natrolite and mesolite rotation photographs about the axis of elongation. Although there is a very marked similarity between the two, many lines are found to be present in the latter which are absent in the former. At first it appeared that the cell-sizes of the two zeolites were the same, the mesolite lacking the systematic halvings shown by natrolite, but when an attempt was made to index the mesolite photographs, and especially when an attempt was made to index a pair of oscillation photographs about the same axis, over a range of 5° from the positions in which $r(301)$ and $R(\bar{3}01)$ respectively are

[1] S. J. Thugutt (1912) described mesolite from the last locality, but his method of diagnosis was not reliable, and J. E. Hibsch (1915) failed to confirm it. The British Museum material is quite unlike that described by Thugutt, being tiny cappings on natrolite needles.

parallel to the X-ray beam,[1] many diffractions could not be satisfactorily indexed. Rotation photographs of mesolite were therefore taken about the *b*- and *c*-axes, when it became clear that the cell-side *a* has approximately treble the length of the corresponding cell-side (*b*) of natrolite. It was then possible to index the photographs satisfactorily, and also to index oscillation photographs about the *a*- and *c*-axes.

When the photographs had been indexed, it was found that all planes of the type (*hkl*) with $(h+k)$, $(h+l)$, or $(k+l)$ odd are halved, indicating a face-centred lattice. There are probably no other systematic halvings. Diffractions from several planes of the types (*h*0*l*), with $(h+l)$ not a multiple of 4 were observed, e.g. (604), (406), and (10.0.20). All these reflections are at most weak. No reflections from planes of the type (0*kl*) with $(k+l)$ not a multiple of 4, or of the type (*hk*0) with $(h+k)$ not a multiple of 4 were observed, but the number of such planes which could be sought for was limited.

Lauegrams show no evidence of departure from orthorhombic symmetry, but the optical data prove that the symmetry must be monoclinic, and in conjunction with the pyroelectric effect and the systematic halvings, point to the space-group C_2^3. Apart from the optical properties there is no evidence of any departure from the space-group C_{2v}^{19}, with *b*-axis polar.

The cell-sides are *a* 56·7 ± 0·1, *b* 6·54 ± 0·02, *c* 18·44 ± 0·04 Å., and the interaxial angle, β, is 90° 0′ ± 20′. The number of oxygen atoms per unit cell has been calculated from the cell-sides, specific gravity, and chemical data for each of the analysed specimens, with the results included in table I.

When base-exchange products were being examined, it was desirable to be able to distinguish readily between a mesolite and a natrolite. A rotation photograph about the *c*-axis of mesolite (*b* of natrolite) would do this easily, but when the rather imperfect crystals of base-exchange products are in question, the setting of this axis vertical is difficult, and it proves simpler to take a rotation photograph about the axis of elongation. On such photographs of mesolite, using Cu-K radiation, if given adequate exposure, using a small crystal, diffractions are observed on the equator at[2]

[1] No differences could be detected between these two photographs, made on a carefully selected untwinned fragment. This emphasizes the marked pseudo-orthorhombic nature of mesolite.

[2] For the cylindrical co-ordinates, ξ and ζ, used for rotation photographs, see J. D. Bernal, Proc. Roy. Soc. London, Ser. A, 1926, vol. 113, p. 117. [M.A. 3–333.]

ξ 0·39, 0·41, 0·63, and 0·64, due to the planes (804), (14.0.2), (14.0.6), and (20.0.4) or (22.0.4) respectively[1]; on the first layer-line at ξ 0·09, 0·16, 0·21, 0·25, 0·29, 0·31, 0·32, 0·37, and 0·39, due to (111), (511), (711), (113), (513), (11.1.1), (713) (13.1.1), and (11.1.3) respectively; and on the second layer-line at ξ 0·18, 0·20, and 0·27, due to (222), (422), and (822). A rotation photograph of natrolite about the elongation (in this case the *c*-, not the *b*-axis) shows no trace of diffractions in these positions, which do not correspond to integral planes of the natrolite lattice. In the base-exchange products, the actual positions of the spots are a little altered, but their positions in relation to the spots common to mesolite and natrolite remain unaltered, and their presence or absence is readily decided, determining the product as a mesolite or natrolite respectively. (See table IX.)

It is hoped to discuss the relation between the structures of natrolite, mesolite, and scolecite as soon as work on the last species, at present in progress, is completed.

Optics.

The optical behaviour of mesolite has been studied by several workers, with rather variable results. G. Cesàro (1909), C. Anderson (1907), and A. Cavinato (1926) found straight extinction on the prism-faces, and on artificial faces in the prism-zone, while most other workers[2] have found distinctly inclined extinction, the extinction-angles given ranging from 1° to 11° on the prism-faces. Cut sections parallel to the *a* and *c* axes of crystals from one of the analysed specimens have been examined, but no results have been found not consistent with monoclinic symmetry. Certain apparent anomalies observed have been described and explained in a previous paper.[3]

With the exception of A. Des Cloizeaux (1862) and E. Hussak (1890, loc. cit.), all workers are agreed that at the ordinary temperature the optic axial plane of fully hydrated mesolite is perpendicular to the elongation (*b*-axis), the positive bisectrix lies in the obtuse normal-angle of the prism, and at room-temperature the optic axial angle is very large, positive (at least for the red end of the spectrum), and

[1] These are in addition to the diffractions given by natrolite in the same region.

[2] A. Des Cloizeaux, 1862; O. Luedecke, 1881; A. Lacroix, 1897; A. N. Winchell, 1900; H. L. Bowman, 1908; R. Görgey, 1909; J. E. Hibsch, 1917.

[3] M. H. Hey, A possible source of error in the determination of symmetry from optical extinction-angles. Min. Mag., 1933, vol. 23, p. 367.

very sensitive to change of temperature or of wave-length. The birefringence is very low, so that the needles appear isotropic under the microscope—a useful means of identification.

Plates of mesolite cut perpendicular to the elongation show a division into sectors which do not extinguish simultaneously. The usual appearance is that shown in fig. 1, two small sectors twinned on and bounded by $a(100)$ or $c(001)$ or both (as β is nearly 90° 0′, these alternatives cannot be distinguished) being based on an opposite pair of prism-faces of the main crystal. Measurements of the principal extinction-angle ($\alpha : c$-axis) gave a value of 8·0°, independent of wave-length, and not affected by moderate changes of temperature. The optic axial angle, 2V, was measured on crystals immersed in a liquid of the same refractive index as the crystals, with the results discussed below, a check on the principal extinction-angle being obtained at the same time.

Refractive index determinations were made for a series of wave-lengths on a cut prism from specimen no. 3. Only the index β was measured, at a temperature of 18–20° C. (table IV, and fig. 2).

Table IV. Refractive indices (β) of mesolite (specimen no. 3) for light of various wave-lengths.

λ (Å.)	β.	λ (Å.).	β.
7000	1·5037	5461 (Hg green) ...	1·5092
6708 (Li)	1·5049	5350 (Tl)	1·5098
6563 (H)	1·5056	5200	1·5110
6250	1·5062	5000	1·5119
6000	1·5071	4861 (H)	1·5126
5893 (Na)	1·5074	4550 (Cs)	1·5147
5708 (Hg yellow) ...	1·5081	4358 (Hg violet) ...	1·5150

Mean probable error ±0·0010 in the absolute values of β; in the relative values for any two wave-lengths, ±0·0002.

As R. Görgey (1909) showed, the optic axial angle of mesolite is highly sensitive to temperature. He found that at 10° C. the mineral is optically positive for all colours, but with rise of temperature $2V_\gamma$ increases and the mineral becomes negative for all colours at about 30° C.; $2V_\alpha$ continues to fall rapidly, and at about 35° C. a uniaxial point appears, after which the optic axial plane becomes parallel to $a(100)$, α being the acute bisectrix for all colours, while γ is now parallel to the elongation. The extinction-angle on $b(010)$ is not noticeably altered during these changes. There is no loss of water by the mineral during the changes, which are perfectly reversible on cooling.

The author has been able to confirm and supplement Görgey's results, though with some quantitative differences which are probably due to small differences in composition. The cut plates used for these studies were made from crystals from specimen no. 3; one plate was cut approximately perpendicular to the *c*-axis, and one perpendicular to the *a*-axis. The optical behaviour of the latter at about 19° C. has already been described.[1] The former, 0·94 mm. thick, proved

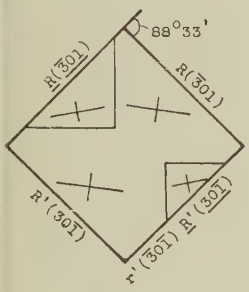

Fig. 1.

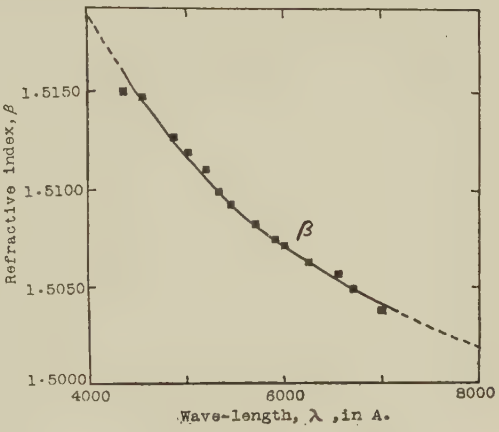

Fig. 2.

Fig. 1. Optic orientation and twin-structure of mesolite, as seen on a section perpendicular to the *b*-axis (elongation) of a crystal from specimen no. 3 (Syhadree Mts.).

Fig. 2. Variation of the refractive index (β) of mesolite (specimen no. 3) with the wave-length of light.

less suitable for accurate study, since the three portions in twin position, of which it is composed, overlap very considerably, resulting in too low values for the birefringence and for the temperatures of uniaxiality. The use of cut plates with the twinned portions overlapping may in some measure account for Görgey's lower figures for the temperatures of uniaxiality, but it is believed that the principal cause is the different composition of his material, which was much richer in sodium than that employed in the present work. It was noticed (loc. cit.) that the cut plate perpendicular to the *a*-axis showed growth-banding of more and less birefringent portions with different optic

[1] M. H. Hey, Min. Mag., 1933, vol. 23, p. 367. A different setting was used, and the plate is there described as approximately perpendicular to the *c*-axis, the present *a*- and *c*-axes being interchanged.

axial angles. Variations in composition during the growth of the crystal appear to be the only reasonable explanation for this. Unfortunately, time did not permit of a detailed examination of the other analysed specimens, nor were they so suitable for the preparation of cut plates.

Each of these cut plates was examined mounted on the Miers stage-goniometer, on a Dick microscope, and immersed in a small cell containing a mixture of xylene and chlorbenzene adjusted to have about the same refractive index as the crystal. A thermocouple built into the cell was used to determine the temperature, which was varied by dropping in hot liquid from a reservoir, the level in the cell being kept steady by a syphon and constant-level device.

The results of the measurements of the birefringence and optic axial angle of mesolite at various temperatures, made with these plates and apparatus, are shown in figs. 3 and 4 and tables V and VI. Only the plate perpendicular to the *a*-axis proved satisfactory for birefringence measurements, plates perpendicular to the *c*- and *b*-axes showing overlapping of the twin portions. On this plate $\beta - a$ (above 55–60° C. $\gamma - a$) was measured at several temperatures and found to

TABLE V. Birefringence $\beta - a$ ($\gamma - a$ above 55–60° C.) of mesolite (specimen no. 3) for several temperatures. Observed values and values calculated from a smoothed curve. Probable error about ±0·00010.

Temp. ...	22·2°	37·2°	52·3°	67·3° C.
$\beta - a$ obs. ...	0·00095	0·00102	0·00118	0·00129
$\beta - a$ calc. ...	0·00095	0·00107	0·00120	0·00131

TABLE VI. Optic axial angles ($2V_\alpha$) of mesolite (specimen no. 3) for various temperatures and wave-lengths. Calculated values from the equations deduced for the birefringences. Optic axial plane parallel *b*(010) except for these values marked *, for these parallel *c*(001).

t.	λ6708 Å.	6250.	5893.	5461.	5350.	5000 Å.
0° C.	108°	107½°	107°	106½°	106°	105½°
10	101	100	99	98½	98	97
20	92	91	90	89½	89	88
30	82	80	79	77½	77	76
40	71	68	66	64	63	61
45	63	60	57	54	53	51
50	55	50	46	42	41	38
55	42	35	31	25	23	15
60	20	0	17*	25*	28*	33*
65	29*	36*	40*	44*	45*	49*
70° C.	46*	59*	53*	56*	58*	61*
Uniaxial at ...	62° C.	60°	59°	57·5°	57°	56° C.

increase appreciably with rise of temperature, while being practically independent of the wave-length of the light. The equation $\beta - \alpha = (7{\cdot}7 + 0{\cdot}08t)10^{-4}$, where t is the temperature in °C., expresses satisfactorily the variation in this birefringence.

Next, the birefringences $\gamma - \beta$ and $\gamma - \alpha$ ($\beta - \alpha$ above 55–60° C.) were

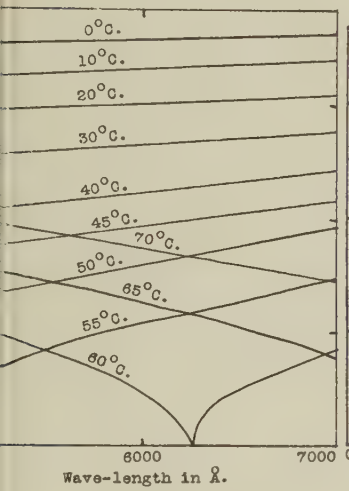

Fig. 3.

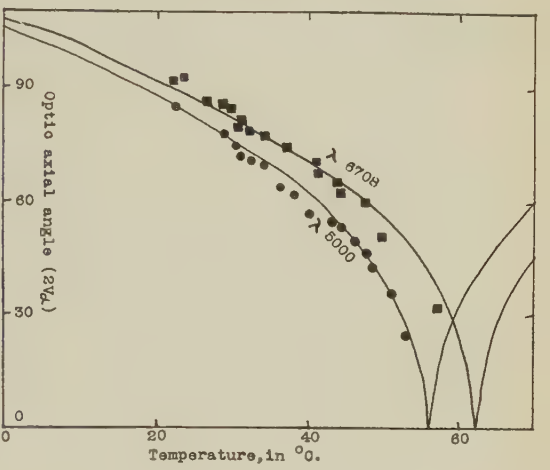

Fig. 4.

Fig. 3. Variation of the optic axial angle of mesolite (specimen no. 3) with the temperature and with the wave-length of light.

Fig. 4. Variation of the optic axial angle of mesolite (specimen no. 3) with the temperature, for light of wave-lengths λ 6708 and 5000 Å. Measured values and calculated curves.

calculated from the measured optic axial angles and the appropriate values of $\beta - \alpha$. The equations

$$\gamma - \alpha = \{21{\cdot}1 - 0{\cdot}16t + 0{\cdot}82 \times 10^{-3}(\lambda - 5000)\}10^{-4} \text{ and}$$
$$\gamma - \beta = \{13{\cdot}4 - 0{\cdot}24t + 0{\cdot}82 \times 10^{-3}\ (\lambda - 5000)\}10^{-4}$$

express satisfactorily the variations in these birefringences with temperature (t in °C.) and wave-length (λ in Å.).

From the equations the optic axial angles were calculated, for a series of temperatures, for each of the wave-lengths used (table VI). The agreement between the measured and calculated values is satisfactory (compare fig. 4, where the curves for λ 6708 and 5000 Å. are shown; the other curves, not reproduced to avoid confusion, agree equally well), and hence there seems no point in reproducing all the measured values.

Measurements on the plate cut perpendicular to the *c*-axis gave confirmation of the general behaviour of the optic axes, but owing to the overlapping of the twin portions, the quantitative results were of no use.

Vapour-pressure.

An investigation of the vapour-pressure (*pct*) surface of mesolite was made with the apparatus and by the methods employed for thomsonite and natrolite and described in Parts II and III of this series (loc. cit.). A series of isohydric curves interpolated from the experimental curves is shown in fig. 5, and isobaric curves computed from them in fig. 6; the latter will be seen to give fairly good agreement with the results of previous workers,[1] plotted in the same figure. Values of the heat of hydration,[2] Q, and of the integration constant, A, of the equation $\log_{10} p = A - Q/(RT \log_e 10)$, for various degrees of hydration, are plotted in fig. 7, and tabulated in table VII. The agreement between the observed pressures and those calculated from the values of Q and A interpolated from the figures of table VII by means of fig. 7 was throughout at least as good as for natrolite.

TABLE VII. The constants of the vapour-pressure surface of mesolite for a series of water-contents (*c*); heat of hydration, Q, and the integration constant, A, of the equation $\log_{10} p = A - Q/(RT \log_e 10)$.

c.	Q, cals.	A.	*c*.	Q, cals.	A.
64·0	$1{\cdot}05 \times 10^4$	8·15	34·0	$2{\cdot}60 \times 10^4$	10·83
63·4	1·24	8·20	31·0	2·67	10·88
62·5	1·43	8·67	28·0	2·74	10·95
61·6	1·91	10·42	25·0	2·82	11·03
61·0	1·97	10·52	22·0	2·90	11·17
58·0	2·14	10·69	19·0	2·19	11·34
55·0	2·20	10·75	16·0	3·06	11·51
52·0	2·25	10·76	13·0	3·13	11·68
49·0	2·30	10·77	10·0	3·20	11·85
46·0	2·34	10·78	7·0	3·28	12·02
43·0	2·39	10·78	4·0	3·36*	12·19*
41·0	2·45	10·78	0·0	$3{\cdot}44^* \times 10^4$	12·36*
37·0	$2{\cdot}52 \times 10^4$	10·79			

* Extrapolated.

[1] Isobaric curves: F. Zambonini, 1908; A. Cavinato, 1927. Rough isobaric curves: L. Pelacani, 1908; T. L. Walker and A. L. Parsons, 1922.

[2] Heat of hydration for one gram-molecule of water absorbed from the vapour phase and exclusive of the external work involved. For further explanation and definition of this and other quantities involved, and the symbols used see Parts II and III, loc. cit.

There seems no necessity for reproducing all the actual measurements as was done for natrolite; the results tabulated for that zeolite (part III; loc. cit., table V) show the order of accuracy attained, and the vapour-pressure to be expected for any composition and

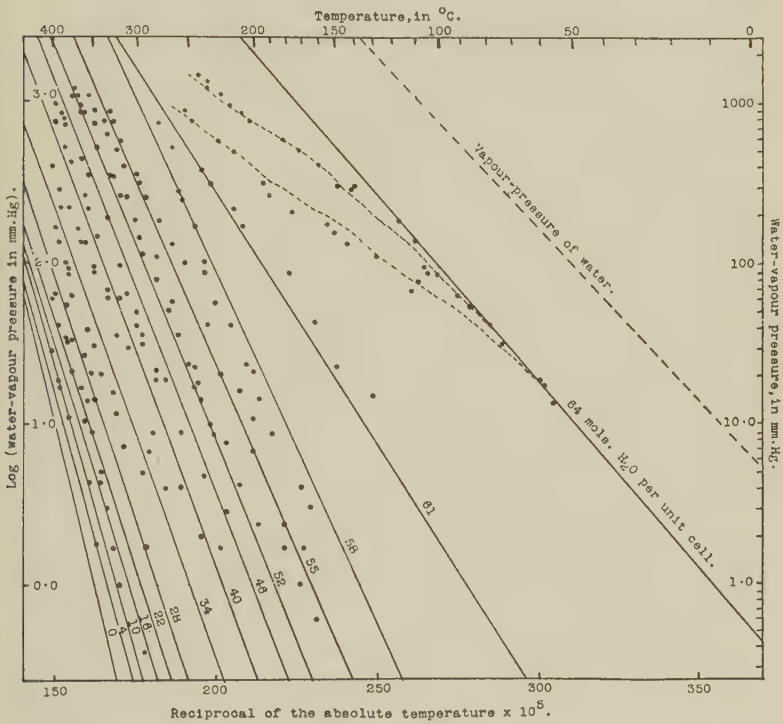

FIG. 5. Isohydric vapour-pressure curves of mesolite (specimen no. 1, from Bh ore Ghaut).

temperature (or the composition or temperature, the other variables being given) may readily be found by the aid of figs. 5, 6, and 7, and the values of Q and A in table VII.

The vapour-pressure surface found for mesolite leaves no possible doubt as to its interpretation. There are no discontinuities anywhere in the surface or in its curvature. Hence we have throughout a single solid phase. Mesolite on dehydration undergoes no transition, but loses its water continuously, and Cavinato's metamesolite (1927) is not to be regarded as a separate species, but merely as the

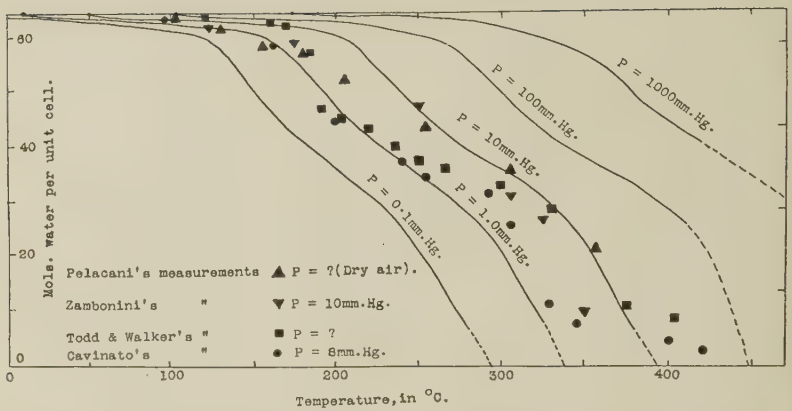

FIG. 6. Isobaric dehydration curves for mesolite calculated from the vapour-pressure measurements. Together with dehydration data from the literature.

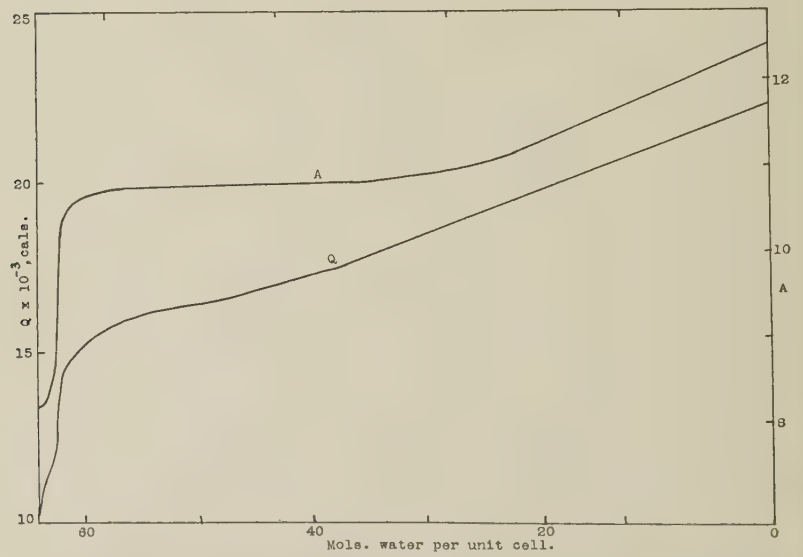

FIG. 7. The variation, with the water content, of the molecular heat of hydration (Q) of mesolite, and of the integration constant (A) of the equation $\log_{10}p = A - Q/RT(\log_e 10)$.

end-member of the isomorphous series of variously hydrated mesolites.

This is confirmed by a study of the effect of dehydration on the optical properties of mesolite (table VIII and fig. 8). As with thomsonite and natrolite, the refractive indices fall rapidly in the initial stages of dehydration, to rise again in the later stages. Unfortunately, partially dehydrated mesolite absorbs water-vapour from the air too rapidly to allow of accurate X-ray measurements of

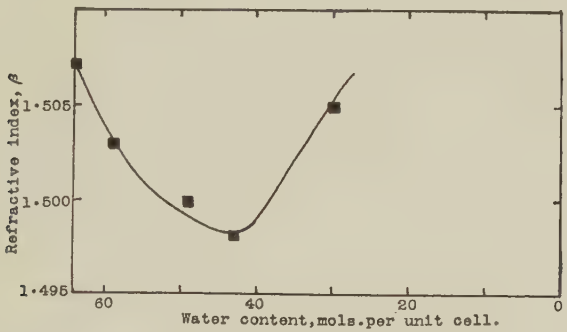

FIG. 8. The variation of the mean refractive index of mesolite (specimen no. 1) with the water content.

its cell-size being made, so it cannot be decided how far the rise in refractive indices in the later stages of dehydration is due to lattice-shrinkage, and how far to increasing polarization of the various atoms as the water is removed. When mesolite is almost completely dehydrated, absorption of water-vapour is much slower, but X-ray study then shows that the crystal-structure has largely broken down. No definite changes of cell-size or intensities of diffraction could be detected.

TABLE VIII. The variation of the mean refractive index of mesolite (specimen no. 1) during dehydration. Yellow light.

Water content, mols. per unit cell ...	64	59	49	43	30
Refractive index	1·507	1·503	1·500	1·498	1·505

Since partially dehydrated mesolite absorbs water so rapidly, a check on the heat of hydration was possible. The same method and apparatus were used as for natrolite.[1] Partially dehydrated mesolite (2·5381 grams mesolite, dehydrated to a loss of weight of

[1] Part III of this series, Min. Mag., 1932, vol. 23, p. 275.

0·1725 grams, leaving 33·7 mol. H_2O per unit cell) was thrown into water in a crucible, the water-equivalent of the crucible and contents being 15·18 grams[1]; the temperature rose 4·6° C. in three minutes, and then began to fall; extrapolated to zero time, the rise is 4·9° C., whence the mean heat of hydration of mesolite by water-vapour, over the range 64 to 34 mols. per unit cell, and exclusive of the external work, is found to be 18,000 cals. per gram-mol. of water absorbed. The value computed from the vapour-pressure measurements is 17,000 cals., in reasonable agreement considering the approximate nature of the calorimetry and the difficulty of ascertaining exactly the slope of the isohydric curves.

An X-ray examination of a partially dehydrated mesolite containing about 30 mols. H_2O per unit cell indicated a considerable breakdown of the lattice, the photograph being very weak. A very unexpected and inexplicable result is that the cell size was found to be a 56·8, b 6·53, c 18·56 Å.—a larger cell than that of the fully hydrated mesolite.

Base-exchange.

The base-exchange reactions of mesolite are of considerable interest, since they furnish a possible means of testing the assumption, commonly made, that natrolite, mesolite, and scolecite are isostructural.

J. Lemberg (1876) treated mesolite with hot potassium chloride solution, and obtained a product approximating in composition to $K_2Al_2Si_3O_{10}.2H_2O$, and by treating this with sodium chloride solution, a product having approximately the composition of natrolite was obtained. Lemberg, however, did not examine his products optically, so that their identity with natrolite and potassium-natrolite was never fully established. Moreover, under his experimental conditions it was possible that the mesolite might dissolve up and natrolite crystallize out rather than a simple base-exchange occur.

G. Steiger (1905) treated mesolite with a fusion of thallous nitrate, at 240–280° C., and obtained a product approximating to $Na_{0·4}Tl_{19·6}Ca_{2·5}Al_{16}Si_{24}O_{80}.17·3H_2O$. He did not examine this product optically, nor did he compare it with thallous-natrolite, which he had previously prepared. The composition is practically the same as

[1] The water-equivalent is, of course, the water-equivalent of the crucible, plus that of the (fully hydrated) mesolite originally taken, plus the weight of water put in the crucible, minus the weight of water lost by the mesolite (and re-absorbed during the experiment). The specific heat of mesolite was assumed to be 0·24, near that of natrolite.

that of the thallous-mesolite described below, which suggests that Steiger's product was also a mesolite.

The author has already shown [1] that a four-months digestion of natrolite with calcium chloride results in a considerable base-exchange, which does not, however, go so far as to produce mesolite. Mesolite (no. 1, from Bhore Ghaut) treated with cold saturated solutions of sodium carbonate, sodium chloride, or calcium chloride for $2\frac{1}{2}$ years, showed no appreciable base-exchange, and optical examination revealed no trace of natrolite or scolecite.[2]

More success was attained in base-exchange experiments with salt fusions. With sodium chlorate at 270° C., $\frac{1}{3}$ of the calcium was replaced in 48 hours, while fusions of silver, thallous, and ammonium nitrates replaced part of the calcium and all or nearly all the sodium. Potassium and lithium nitrate fusions readily replaced all the sodium and nearly all the calcium. The products were all analysed and examined optically, and X-ray rotation photographs were taken of those which had not broken up into powder. The results are shown in table IX.

The lithium compound was homogeneous, and agreed in all respects (chemical, optical, and X-ray) with the lithium derivative prepared from natrolite.[3] Its X-ray rotation photograph showed no trace of the extra spots, above mentioned, which serve as a useful criterion for the distinction of mesolite and natrolite. Hence this compound prepared from mesolite is actually lithium-natrolite, and its preparation provides the first decisive proof that natrolite and mesolite are indeed isostructural.

The potassium compound agreed in chemical composition and optical properties with potassium-natrolite, and is certainly identical with the latter, though the proof could not be made so conclusive as for the lithium compound, since the material prepared from natrolite was a very fine powder so that only Debyeograms could be taken. But that prepared from mesolite was more coarse-grained and gave

[1] Compare Part III of this series, loc. cit., pp. 277 ff.

[2] Complete chemical analyses of these products were made, but there seems no point in reproducing them, as no change is revealed.

[3] The latter was formerly described (Part II of this series, loc. cit., and W. H. Taylor *et al.* (1933)) as having a 17·95, b 18·55, c 6·47 Å. These values are inaccurate; new measurements give a 17·84, b 18·63, c 6·47 Å., in better agreement with the compound prepared from mesolite (see table IX). More accurate measurements were also made of the ammonium-natrolite previously described, and the cell-sides were found to be a 17·96, b 18·35, c 6·55 Å., all $\pm 0{\cdot}02$ Å.

TABLE IX. Experiments on base-exchange, with Bhore Ghaut mesolite (specimen no. 1).

			Treated with a salt fusion:					
		Untreated.	270° C. 70 hrs. $NaClO_3$.	200° C. 48 hrs. KCNS.	270° C. 70 hrs. $LiNO_3$.	180° C. 48 hrs. NH_4NO_3.	180° C. 48 hrs. $AgNO_3$.	270° C. 96 hrs. $AgNO_3$.	220° C. 48 hrs. $TlNO_3$.
				¶	¶			¶	
Percentage composition.	SiO_2 ...	46·05	47·15	43·82	50·70	49·96	38·88	39·30	28·60
	Al_2O_3 ...	26·84	28·26	24·82	29·50	27·86	22·87	22·47	18·13
	CaO ...	10·00	6·74	2·49	2·08	8·55	5·59	6·03	2·90
	Na_2O ...	3·82†	8·14	nil	nil	nil	1·76	nil	0·58
	R_2O* ...	—	—	18·51	6·36	6·37‡	20·86	27·21	[42·75] ‖
	H_2O ...	12·30	10·49	10·32	10·46	7·58‡	9·47	5·91	7·04
	Total ...	99·80	100·78	99·96	99·10	100·32	99·43	100·92	[100·00]
Oxygen % ...		41·21	42·11	39·71	45·34	43·97	35·23	34·79	26·35
Oxygen, atoms per unit cell.		240·5	242 ?	82·8 ?	80·2	241·7	245 ± §	83·0 ±	—
Atoms per 80 atoms oxygen.	Si ...	23·6	23·7	24·0	24·0	24·1	23·2	23·9	23·1
	Al ...	16·6	16·7	16·0	16·5	15·9	16·9	16·1	17·3
	Ca ...	5·6	3·6	1·5	1·0	4·4	3·7	3·9	2·5
	Na ...	3·9†	7·9	nil	nil	nil	2·1	nil	0·9
	R* ...	—	—	12·9	12·2	7·1	6·8	8·6	9·8
	H_2O ...	21·5	17·6	18·9	16·5	12·2	19·8	12·0	19·0
Sp. gr. ...	...	2·259	2·22 ?	2·22 ?	2·19	2·144	2·63–2·75	2·8 ±	2·35 ±
Mean refractive index for Na-light		1·5074	1·499	1·483	1·491	1·511	1·542	1·552	1·588
Birefringence ...		0·002	0·004 ± 0·010		0·013	variable, very small	0·004 ± 0·002		very small
Optic orientation; elongation =		β	γ	γ	γ	—	α	α	γ
Cell-sides in Å.	a ...	56·7	56·3	19·27	17·61	56·4	56·7	18·30	—
	b ...	6·54	6·54	19·77	18·65	6·53	6·53	18·90	—
	c ...	18·44	18·58	6·51	6·49	18·38	18·42	6·51	—
	r* ...	0·98	0·98	1·33	0·68	1·44	1·5 ?	1·5 ?	1·7 ?
Water left, in mols. per 80 oxygen	110° C.	21·4	16·2	2·6	16·2	11·5	19·5	11·7	8·3
	300° C.	7·0	0·5	0·9	3·2	nil ?	3·9	2·4	5·0

* R indicates the kation of the salt employed in the base-exchange, and r is its radius in Å.

† Also 0·79 % K_2O, or 0·53 atoms K per 80 oxygen.

‡ The estimation of NH_3 and H_2O in this material was made by the method described in Part III of this series, loc. cit., p. 278, footnote.

‖ By difference.

¶ The optics, water contents, and X-ray data show these products are natrolites and not mesolites.

§ Taking the sp. gr. as 2·69; if it is taken as 2·63, the oxygen content comes to 239 atoms per unit cell.

fairly good rotation photographs, on which the critical spots were definitely absent.

Two silver compounds were prepared, one by the action of silver nitrate at 180° C. for 48 hours, the other by treatment for 96 hours at 270° C.; neither was completely homogeneous, as shown by the variable refractive indices and densities. The product treated for the shorter time and containing least silver, was shown by X-ray photographs to be still a mesolite, the critical diffractions being all present; in agreement with this, its water content was higher (19·8 mols. per 80 oxygen) than that of natrolite (16 mols.). The compound richer in silver, on the other hand, was found to be a silver-natrolite, a result confirmed by its low water content. The silver-mesolite had a higher birefringence than this silver-natrolite, and a lower refractive index and density. The silver-natrolite prepared from mesolite still contained a considerable amount of calcium, and on comparing it with the lime-free compound prepared from natrolite (which also contains more silver) it will be seen that the birefringence is higher, the refractive index and density lower than those of the latter; there were also distinct intensity differences in the X-ray photographs.

By the action of an ammonium nitrate fusion, a compound was prepared which an X-ray photograph showed to be an ammonium-mesolite. This material had a very low birefringence and was zoned, the outside of the crystals having a positive elongation and the centre a negative one, with an isotropic zone between.

Thallous nitrate gave a base-exchange product consisting of a fine powder, of which no X-ray examination could profitably be made; judging from its high water content, it is a thallous-mesolite.

By the action of a sodium chlorate fusion on mesolite, it was hoped that natrolite would be produced; the product actually obtained had a higher birefringence and lower refractive index than mesolite, and its optical orientation was $\gamma = b$ (axis of elongation of the needles), but an X-ray photograph showed that it was still a mesolite. It is probable that the optical changes are due rather to its lower water content than to the replacement of calcium by sodium; even after soaking in water it only contained 18 mols. water per 80 oxygen. It may be noted that the decrease in water content is approximately equal to the increase in sodium, but this can hardly be more than an accidental relation, for in the transformation of mesolite into natrolite, twelve sodium atoms are taken

up, but only six water molecules are lost (calculated on a basis of 80 oxygen). Probably the effect of the introduction of sodium is simply to increase the water-vapour pressure at any given temperature and water content.

A study of the effect of base-exchange on the vapour-pressure of a suitable zeolite should prove of considerable interest. Time did not permit of this being carried out, but for a rough comparison, each of the base-exchange products was dehydrated at 110° C. and at 300° C.; no attempt was made to regulate the water-vapour pressure, but as all the specimens were heated together in the same oven, it is approximately the same for all, so permitting of comparison. The water-vapour pressure was probably about 1–3 mm. Hg.

The introduction of extra sodium into mesolite (in place of calcium) is seen to lead to a greater loss of water both at 300° C. and 110° C., indicating a marked increase in the vapour-pressure, as suggested above. Ammonium (replacing all the sodium and part of the calcium) also caused an increase in the vapour-pressure, as was to be expected from its large ion. Thallium, with a still larger ion, caused a still greater loss of water at 110° C., but the loss at 300° C. was less than for the ammonium-mesolite, and of the same order as that of mesolite itself. Silver, on the other hand, with an atomic radius probably intermediate between those of ammonium and thallium, had little effect on the water loss at either temperature. The reason for this behaviour is quite obscure.

The base-exchange products prepared from natrolite [1] were not studied in respect of their dehydration. But the potassium-, lithium-, and silver-calcium-natrolites now prepared from mesolite were included in the above series of dehydration experiments. At 110° C. natrolite itself will retain about 15 mol. water per unit cell, at 300° C. nil.[1] Replacement of sodium by lithium with a smaller atomic radius is seen to favour retention of the water, as might be expected, while the larger potassium atom favours its loss. Indeed, the effect of potassium is so great that while natrolite itself only loses most of its water at about 230° C. at 1 mm. Hg, potassium-natrolite has lost nearly all of it at 110° C. Silver, although its atomic radius is probably greater than that of potassium,[1] only causes a small increase in the loss of water at 110° C., and at 300° C. the loss is probably less than for natrolite itself. Ammonium, an ion somewhat larger than potassium, evidently has an even greater effect

[1] Part III of this series, loc. cit.

on the affinity of natrolite for water than has potassium, for the ammonium-natrolite was anhydrous.[1] The large thallium ion, on the other hand, had a less effect than ammonium (contrary to the case with mesolite), for the author obtained thallous-natrolite hydrated;[1] Steiger's thallous-natrolite, though prepared in the same manner, was, on the other hand, anhydrous, so the thallium ion must decrease the affinity of natrolite for water very markedly.

Summary.

Mesolite is an independent species, isostructural, but not isomorphous with natrolite and scolecite. Five new analyses have been made. The unit cell, of dimensions a 56·7, b 6·56, c 18·44 Å., β 90°0′, contains $Na_{16}Ca_{16}Al_{48}Si_{72}O_{240}.64H_2O$. The space-group is C_2^3, but there is a marked approximation to the orthorhombic space-group C_{2v}^{19}. Goniometric measurements are in excellent agreement with the X-ray data, and show a marked development of vicinal pyramids. The optical properties, vapour-pressure, and base-exchange of mesolite have been studied in considerable detail. It has been found possible to make a ready distinction between mesolite and natrolite by X-ray methods, and it has been shown that by the action of fusions of potassium thiocyanate, lithium nitrate, and silver nitrate on mesolite, compounds identical with similar derivatives prepared from natrolite may be obtained; these have the natrolite structure. The vapour-pressure measurements have been checked by a direct determination of the heat of hydration of partially dehydrated mesolite. Mesolite has been observed on specimens from eight localities new for the species.

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On a new barium plagioclase felspar.

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In the memoir dealing with the geology of the Broken Hill district, New South Wales, mention is made[1] of a remarkable rock type found in a few places in the vicinity of Broken Hill, which looks not unlike an aplite in the field. A brief description of its appearance in thin section is given. It consists mainly of what appears to be very basic plagioclase. A fair amount of quartz, some epidote and bluish-green hornblende were noticed, whilst a notable amount of sphene is present. The rock was analysed by H. P. White with the result quoted below (p. 454). This analysis proved the rock to be unique in its barium content. The authors supposed the barium to be contained in the felspar, but a calculation showed that there was not enough alumina present in the rock to satisfy the felspar formula, assuming all the barium and lime to be present in that mineral. They remarked that the matter must remain unexplained for the present.

The present investigation was undertaken in order to explain the discrepancy in alumina, noted above, and to obtain further particulars about the felspar. For this purpose the original analysed specimen (B. 222) was used.

In thin section the rock is granular in texture, and is composed mainly of a plagioclase felspar and quartz. The quartz usually shows a development of strain shadows. The 'epidote' referred to in the original description is fairly common and is, in reality, a clinozoisite with $\gamma : (001)$ cleavage $= 22°$, biaxial, positive. The sphene is a brown, granular variety which is pleochroic from pale to darker brown. It may sometimes be rimmed with clinozoisite. Occasionally a little ilmenite occurs as cores to some of the sphene. The green hornblende, present in small quantity, has positive elongation, is biaxial negative

[1] W. R. Browne, Appendix I of Mem. Geol. Survey, N.S.W., 1922, no. 8, p. 337.

with $\gamma : c = 17°$ and α pale yellowish-green, β dull green, γ greenish-blue. Apatite is not uncommonly present, chiefly as needles enclosed in felspar. Finally, there is a certain amount of orthite present as crystals which have been more or less altered. This orthite may be rimmed with clinozoisite. When the crystals of orthite are enclosed in felspar, the felspar is traversed by a series of cracks stretching out from the orthite. These have no doubt been caused by expansion during the alteration of the orthite.

Fig. 1. Thin section showing twinning in the barium plagioclase. Crossed nicols. ×24.

The mode of this rock measured on a Leitz integrating stage is:

	Volume %.	Assumed sp. gr.	Weight %
Quartz	37·52	2·65	35·05
Plagioclase ...	53·22	2·872	53·88
Clinozoisite ...	6·28	3·36	7·44
Sphene	2·28	3·48	2·80
Orthite	0·56	3·43	0·67
Fe-Mg minerals and apatite ...	0·14	3·24	0·16
	100·00		100·00

The plagioclase felspar is present as grains (fig. 1) which look very much like those of any other plagioclase. The average size of the grains is 0·55 × 0·40 mm. The largest grain measured was 1·66 × 1·00 mm.,

the grain size of the quartz being rather less. A number of these plagioclase grains were examined on the universal stage. The readings and results are detailed below:

		α.	β.	γ.	Twinning-type.	2V.
Crystal 1.	T* ...	50°	63½°	49°	Albite-Ala B	−80°
	P* ...	66½	56	42		
,, 2.	T ...	55	55	54	Albite-Ala B	−82
	P ...	68	63	36		
,, 3.	T ...	51	64	50	Albite-Ala B	−74
	P ...	69½	54	43½		
,, 4.	T ...	54½	62	51	Albite-Ala B	−80
	P ...	69	55½	40½		
	T ...	34	58	84	Ala B	—
	P ...	71	52	40		
	T=P ...	73	48½	42	Albite	—
,, 5.	T ...	67½	32½	67	Albite-Carlsbad A	−74
	P ...	51	71	47		and −80
	T=P ...	51	50	58	Manebach	—
,, 6.	T=P ...	68	61	38	Albite	−78
,, 7.	T=P ...	60	70	36	Albite	−78
	T=P ...	50	64	50	Manebach	—
,, 8.	T=P ...	55	60½	45	Manebach	−78
,, 9.	T=P ...	76	56	34	Albite	−78
,, 10.	T ...	38	81	50	Carlsbad A	−78
	P ...	53	68	47		
	T=P ...	61	59	42	Albite	—
	T=P ...	53	62	49	Manebach	—

* T = pole of twin-axis, P = pole of twin-plane.

When these results are plotted the points fall quite close to the twinning curves given by Duparc and Reinhard,[1] usually at between 70 % and 80 % anorthite, the slight discrepancy found being due, no doubt, to the unusual composition of the felspar with which we are dealing.

The following types of twinning have thus been recognized:

Normal hemitropy.	Parallel hemitropy.	Complexes.
Albite	Carlsbad A	Albite-Carlsbad A
Manebach	Ala B	Albite-Ala B
	Pericline	

Of these the albite and the albite-Ala B twinning types were a good deal more abundant than the others. A feature of this felspar is that the albite lamellae are usually very narrow.

[1] L. Duparc and M. Reinhard, Mém. Soc. Phys. Hist. Nat. Genève, 1924, vol. 40, fasc. 1, plate 9. [Min. Abstr., vol. 3, p. 34.]

The optic axial angle (2V) was found to vary from 74° to 82° in various examples, with an average value of 78°. The optic sign is negative. Dispersion is very weak with $\rho < v$.

By a fortunate chance one crystal measured was oriented normal to the zone [(001) (010)]. The following data, obtained on the universal stage, could then be plotted directly on to a stereographic projection normal to the above zone:

	Circle A_1.	Circle A_2.
Axis $A_4 \parallel \gamma$	0°	0°
,, $\parallel \alpha$	90	34
,, $\perp$ cleavage (010) ...	216	0
,, $\perp$,, (001) ...	129	0

β could then be plotted, and the average value of $-78°$ was taken as the distance between the optic axes. The results are shown in fig. 2 together with similar data for certain normal plagioclases.[1]

The indices of refraction were obtained on the universal stage, using Kinzo Nakashima's method,[2] and also from grains, using the immersion method. The two sets of results are compared below:

	Universal stage.	Immersion method.
n_α	—	$1{\cdot}571 \pm 0{\cdot}002$
n_β	$1{\cdot}579$	$1{\cdot}580 \pm 0{\cdot}002$
n_γ	$1{\cdot}585$	$1{\cdot}585 \pm 0{\cdot}002$

Amongst the other optical properties, the maximum extinction-angle on symmetrical albite lamellae was found to be 40°. The inclination of pericline lamellae to the (001) cleavage was 18°. Extinction-angles on cleavage flakes gave $-26°$ on (001) and $-40°$ on (010). The values calculated from a stereogram by Fresnel's construction were $\alpha' : (010) = -27°$, and $\alpha' : (001) = -41°$ respectively.

Turning now to the physical properties, the (010) and (001) cleavages are both well developed. In many cases the (010) cleavage is more perfect than that following (001). The cleavage angle is approximately 94°. The specific gravity of this felspar was found to be 2·872 at 17° C. The felspar is insoluble in concentrated hydrochloric acid.

It is thus evident that we are here dealing with a plagioclase felspar, but one whose properties do not agree with those of any

[1] Data for other plagioclases from Duparc and Reinhard, loc. cit., p. 18, fig. 7.

[2] K. Nakashima, Journ. Geol., 1926, vol. 34, pp. 235–247.

previously known variety. In the subjoined table a comparison is made between this felspar and some basic plagioclases: [1]

	The barium plagioclase.	Labradorite ($Ab_{45}An_{55}$).	Bytownite ($Ab_{25}An_{75}$).	Anorthite (Ab_0An_{100}).
Specific gravity	2·872	2·69	2·72	2·76
Solubility in HCl	Insoluble	Insoluble	Dissolves slowly	Dissolves readily
Optic axial angle	78°	74°	86°	77°
Optic sign	Negative	Positive	Negative	Negative
n_α	1·571	1·557	1·5645	1·5755
n_β	1·580	1·560	1·5693	1·5832
n_γ	1·585	1·566	1·5735	1·5885
$n_\gamma - n_\alpha$	0·014	0·009	0·0090	0·0130
Dispersion	$\rho < v$	$\rho > v$	$\rho < v$	$\rho < v$

A portion of the rock was crushed and the heavy minerals separated from the quartz and plagioclase by means of bromoform. Quartz was then separated from the plagioclase by diluting the bromoform until the grains of plagioclase sank, whilst those of quartz floated. The separation was repeated several times. Finally, the plagioclase thus obtained was hand-picked until as pure as possible a concentrate remained. This was subjected to analysis with the following results:

	I.	II.	III.	IV.	Mol. ratios of IV.	
SiO_2	46·0	46·0	43·3	44·6	0·743	
TiO_2	0·6	0·6	0·4	—	—	
Al_2O_3	30·7*	30·2*	31·8	33·0	0·324	
Fe_2O_3 † ...	2·2	1·8	1·2	—	—	
CaO	13·3	12·9	14·1	14·0	0·249	
BaO	5·4	5·3	5·5	5·7	0·037	0·326
Na_2O	2·6	2·6	1·9	2·0	0·032	
K_2O			0·7	0·7	0·008	
P_2O_5	—	—	0·3	—	—	
H_2O	—	—	1·0	—	—	
	100·8	99·4	100·2	100·0		

* Includes P_2O_5. † All Fe as Fe_2O_3.

I. Analysis on 50·2 mg. by Na_2CO_3 fusion. Ba and Ca separation based on relative insolubilities of the sulphates. (E.G.Z.)

II. Analysis on 65·8 mg. by the Berzelius method. Ba and Ca separation here based on insolubility of $BaNO_3$ in fuming HNO_3. (E.G.Z.)

III. Average of two analyses on a second sample. Total weight of samples used, 0·3392 gram. (E.G.Z.)

IV. Analysis III calculated to 100 % after allowing for included sphene and apatite and omitting Fe_2O_3 and H_2O.

[1] Data taken from Winchell's Elements of optical mineralogy, 1927, pt. II, pp. 279, 292, 293.

It is found that there is not quite enough silica present to combine with the whole of the soda to form albite, and consequently some of

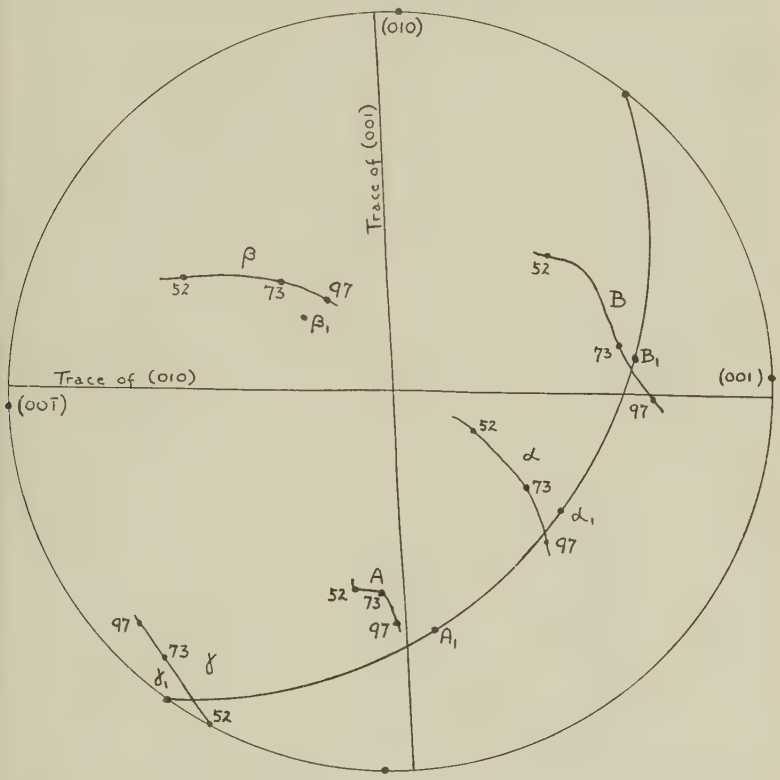

FIG. 2. Stereographic projection on the plane normal to the zone [(001)(010)] plotting the optic axial plane, ellipsoidal axes (α_1, β_1, γ_1), and the optic axes (A_1 and B_1) of the barium plagioclase. The ellipsoidal axes and optic axes for certain normal plagioclases (An 52, 73, and 97 %) are included for comparison.

it must be calculated as carnegieite. The composition of the felspar is then as follows (column I):

	I.	II.
Orthoclase ($KAlSi_3O_8$)	3·9	3·48
Albite ($NaAlSi_3O_8$)	8·9	36·16
Anorthite ($CaAl_2Si_2O_8$)	69·2	53·78
Celsian ($BaAl_2Si_2O_8$)	13·9	—
Carnegieite ($Na_2Al_2Si_2O_8$)	4·0	5·58

The felspar has thus the approximate composition $Or_4Ab_9Cg_4Ce_{14}An_{69}$ and may be described as a barium 'anemousite' or, more

appropriately, as a barium anorthite. The composition of a typical anemousite taken from Washington and Wright's paper[1] is given in column II for comparison. Although our felspar is a more basic variety, yet the amounts of the carnegieite molecule present are not very different. Both Washington and Wright and, more recently, Barth[2] believe that the carnegieite is in solid solution with the plagioclase; while Beljankin[3] suggests the presence of an alkali aluminate in solid solution. As far as the anorthite molecule is concerned experimental evidence is against any appreciable amount of solid solution with carnegieite, and recent work on the structure of the felspars suggests that solid solution is probably not the true explanation, and we are much indebted to Dr. W. H. Taylor for the more probable interpretation now given. The felspar structure is an open one, and it seems likely that the deficiency of silica found in our analysis is due to the replacement of a certain amount of Si by Al

	Partial Analysis of rock (B. 222). (E. G. Zies.)	Analysis of rock (B. 222). (H. P. White.)
SiO_2	62·5	55·12
Al_2O_3	19·1	20·72
Fe_2O_3	1·3*	0·75
FeO	—	0·36
MgO	—	nil
CaO	8·9	10·08
BaO	4·8	9·23
SrO	—	trace
Na_2O	1·0†	1·13
K_2O		0·39
H_2O+	1·5	1·36
H_2O-		0·22
CO_2	—	trace
TiO_2	0·6	0·65
P_2O_5	0·3	0·25
MnO	—	trace
	100·0	100·26‡
Sp. gr.	—	2·887

* All Fe as Fe_2O_3.

† Alkalis by difference.

‡SO_3, Cl, F, Cr_2O_3, NiO, CoO, V_2O_3, Li_2O, ZrO_2, CuO absent.

[1] H. S. Washington and F. E. Wright, Amer. Journ. Sci., 1910, ser. 4, vol. 29, p. 59.

[2] T. F. W. Barth, Journ. Washington Acad. Sci., 1930, vol. 20, p. 60. [M.A. 4–398.]

[3] D. Beljankin, Centr. Min., Abt. A, 1931, pp. 356–364. [M.A., 5–70.]

(with co-ordination number 4) in the fundamental Si–Al–O framework. The extra sodium may then be present in the form of sodium atoms filling up some of the unoccupied spaces in the felspar structure. This is equivalent to suggesting that some of the calcium atoms in the felspar structure may be replaced by two sodium atoms as is the case in some of the zeolites.

The barium content in our analyses of the felspar shows a large discrepancy when compared with that found for the rock as a whole in the analysis made by H. P. White. On the other hand, there does not seem to be a sufficient quantity of any other mineral in the rock to bring the total up, even if we assume that mineral to be rich in barium. To make certain of this point we have made a partial analysis of the rock itself. Our result is given opposite together with H. P. White's analysis.

The norm of our partial analysis, assuming all the alkalis to be Na_2O, is given below together with that of H. P. White's analysis:

	E. G. Z. Analysis.		H. P. W. Analysis.	
Quartz	35·64	... ...	22·38	
Orthoclase	—		2·22	
Albite	8·38		9·43	
Anorthite	38·92	58·94	33·64	67·82
Celsian	11·64		22·53	
Wollastonite	0·46	... ...	5·68	
Haematite	1·28	... ...	0·80	
Apatite	0·67	... ...	0·67	
Sphene	1·57	... ...	0·59	
Ilmenite	—	... ...	0·91	
	98·56		98·85	

The norms of the two may be seen to differ considerably. The norm of our analysis contains a good deal more quartz, almost half the amount of celsian and less than one-twelfth the amount of wollastonite found in the norm from White's analysis. The amount of wollastonite is, of course, an index of the deficiency in alumina required to make all the K_2O, Na_2O, CaO, and BaO into felspar molecules. In our analysis this deficiency equals 0·41 % Al_2O_3, in White's analysis the deficiency equals 4·39 % Al_2O_3. Our analysis is, admittedly, only a partial one, but the alkalis are the only important constituents not directly determined and these cannot be much greater or less than 1 %. The fact that we have assumed the total alkali content to be Na_2O when making the norm actually makes our deficiency of Al_2O_3 appear greater than it really is. This

slight deficiency is probably due to the fact that a little of the lime is present in the rock itself as clinozoisite instead of anorthite, but the deficiency of Al_2O_3 in White's analysis can hardly be accounted for in this manner. As a matter of fact the amount of clinozoisite needed to take up the deficiency can easily be calculated. The amount necessary is 3·63 %. The deficiency of Al_2O_3 in White's analysis cannot be accounted for in this way as calculation shows that in order to take up the deficiency of Al_2O_3 in clinozoisite more lime would be required than is present in the analysis.

Finally, our analysis shows an amount of BaO compatible with the hypothesis that it is all in the felspar, whereas White's analysis demands the presence of another barium-bearing mineral which, if it carries the same percentage as the felspar, should be almost as abundant. It is thus probable that the rock varies in composition and that another barium-bearing mineral such as sanbornite was present in the sample analysed by White. We hope to undertake further work on this interesting material and see if we can establish the presence of another such mineral.

Comparison with other Occurrences.

Both the rock and the plagioclase felspar described appear to be unique. The highest content of BaO recorded in a rock analysis up to the present is 1·1 % in some highly potassic rocks from Wyoming.[1] There seems to be only one record of a previous barium plagioclase, which comes from an unknown locality.[2] Its composition was very different from that of the present example, having SiO_2 55·10, Al_2O_3 23·20, Fe_2O_3 0·45, BaO 7·30, CaO 1·83, MgO 0·56, Na_2O 7·45, K_2O 0·83, volatile matter 3·72 = 100·44; specific gravity 2·835. It was biaxial negative with an extinction-angle $\alpha' : (010)$ of 5° on (001) cleavage plates and $\alpha' : (001)$ of 7° 30′ on (010). According to Eskola,[3] the binary system $CaAl_2Si_2O_8$–$BaAl_2Si_2O_8$ has been investigated by Ginzberg,[4] but we have been unable to see the latter's paper. He found that the triclinic anorthite could take up limited amounts of barium felspar in solid solution, whereby the optic axial

[1] H. S. Washington, Journ. Franklin Inst., 1920, vol. 190, p. 767. [M.A. 1–160.]

[2] A. Des Cloizeaux, Tschermak's Min. Mitt., 1877, pp. 99–100.

[3] P. Eskola, Amer. Journ. Sci., 1922, ser. 5, vol. 4, p. 365. [M.A. 2–153.]

[4] A. S. Ginzberg, Ann. Inst. Polytech. Pierre le Grand, Petrograd, 1915. [M.A. 2–153.]

angle diminishes. This would also seem to be the case with the natural plagioclase, since our barium plagioclase has a lower axial angle than that of the normal plagioclase (between 70 % and 80 % An) to which it most closely corresponds with respect to the position of its optic plane, optic axes, &c., and to the positions of the poles of its twin-planes and axes for the various types of twinning found.

The authors wish to express their best thanks to Professor W. R. Browne, of Sydney University, who, through Professor C. E. Tilley, provided the material, and one of them (S. R. N.) to Dr. F. C. Phillips for first introducing him to the use of the universal stage.

Some relationships between the reflectivities of sulphide ore-minerals.

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[Read November 9, 1933.]

SINCE the early work of Drude and others on the reflection of light by opaque crystalline media, little progress has been made in the direct determination of the indices of refraction and absorption for such substances. Interest in the optical properties of the opaque minerals, however, has been greatly stimulated by the rapid development in the last few years of the methods of ore-microscopy first brought into prominence by Campbell in 1906. Full theoretical discussions have been given recently by Berek,[1] Koenigsberger,[2] and others, but the only quantitative measure feasible in routine microscopy at present is that of the reflectivity. Such measurements are readily carried out by means of a photometer-ocular (Schneiderhöhn,[3] Berek [4]) or a photoelectric ocular (Orcel [5]), and are of very considerable diagnostic value. They do not, however, lead to a determination of the actual values of the indices of refraction (n) and absorption (k); Cissarz [6] has shown, for example, that the theoretically feasible method of determining n and k by measurements of reflectivity (R) in media of different refractive indices fails in practice owing to the large error introduced in the results by a small error in the determination of the reflectivities. An important factor in limiting the application of mathematical theory to practical microscopy lies in the departure from normal incidence involved in the use of an objective below the illuminator, and the resulting variability of the

[1] M. Berek, Zeits. Krist., 1931, vol. 76, pp. 396–430; ibid., vol. 77, pp. 1–22; ibid., vol. 80, pp. 18–36; Neues Jahrb. Min., Abt. A, 1931, Beil.-Bd. 64, pp. 123–136. [Min. Abstr., vol. 5, pp. 122–123.]

[2] J. Koenigsberger, Neues Jahrb. Min., Abt. A, 1931, Beil.-Bd. 64, pp. 107–121.

[3] H. Schneiderhöhn, Centr. Min., Abt. A, 1928, pp. 394–396.

[4] M. Berek, Zeits. Krist., 1931, vol. 77, pp. 6–21.

[5] J. Orcel, Bull. Soc. franç. Min., 1930, vol. 53, pp. 301–349. [M.A. 4–444.]

[6] A. Cissarz, Neues Jahrb. Min., Abt. A, 1931, Beil.-Bd. 64, p. 158. [M.A. 5–125.]

cone of incidence with the aperture of the objective used. It is fortunate that the relative reflectivities are little affected by these factors (Berek,[1] and the author's own measurements), so that comparison of an unknown mineral with one of known reflectivity whilst employing the same set-up remains a useful method of diagnosis. The absolute reflectivities of a few standards are determined from their known physical constants.[2]

The R value therefore remains at present the only constant likely to be determined quantitatively, and largely through the work of Schneiderhöhn and Ramdohr[3] values for a number of sulphide ore-minerals are now available. It seems of interest to examine the results for any evidence of regular relationships.

Amongst the simple sulphides, selenides, and tellurides an increase of reflectivity with increasing atomic number can be traced, the figures in table I being self-explanatory. The more complex minerals, such as the series of sulphantimonites of lead $x\mathrm{PbS}.y\mathrm{Sb_2S_3}$, show less obvious relationships, but the author has recently suggested a method of computation which appears to give interesting results.[4] The absorption index of these sulphides is of secondary importance

TABLE I. Showing increase in reflectivity with increasing atomic number.

Chalcosine	Cu_2S	20	Blende	ZnS	14·5	Orpiment	As_2S_3	26
Argentite	Ag_2S	33	Greenockite	CdS	17	Stibnite	Sb_2S_3	34·2
			Cinnabar	HgS	25·5	Bismuthinite	Bi_2S_3	43
Galena	PbS	37·5	Argentite	Ag_2S	33	Cinnabar	HgS	25·5
Claustha-lite	PbSe	43	Naumannite	Ag_2Se	34·5	Tiemannite	HgSe	27
Altaite	PbTe	55	Hessite	Ag_2Te	40	Coloradoite	HgTe	31
Chalcosine	Cu_2S	20	Stromeyerite	CuAgS	26	Enargite	Cu_3AsS_4	21·5
Berzelianite	Cu_2Se	25	Eukairite	CuAgSe	27	Famatinite	Cu_3SbS_4	23·5
Sartorite	$PbAs_2S_4$	28	Proustite	Ag_3AsS_3	21			
Zinckenite	$PbSb_2S_4$	33	Pyrargyrite	Ag_3SbS_3	27			
Alaskaite	$PbBi_2S_4$	40						

[1] M. Berek, loc. cit., p. 4.

[2] A. Cissarz, Zeits. Krist., 1932, vol. 82, pp. 438–450. [M.A. 5–205.]

[3] H. Schneiderhöhn and P. Ramdohr, Lehrbuch der Erzmikroskopie, vol. 2, Berlin, 1931. [M.A. 4–434.]

[4] F. C. Phillips, Nature, London, 1932, vol. 130, p. 998. [M.A. 5–206.]

only in determining the reflectivity, which is not in this sense true metallic reflection (Wright,[1] Tyndall [2]), and is due mainly to a very high refractive index. It is therefore a reasonable approximation to consider such minerals as transparent in small thicknesses still relatively great compared with the wave-length of the light employed (Orcel [3]). For a transparent substance the refractive index could be calculated from the reflectivity from Fresnel's relationship $n = (1+\sqrt{R})/(1-\sqrt{R})$. If such n values are calculated for these sulphides, they may then be used to derive from the Lorenz-Lorentz equation for the molecular refractivity, $MR = M(n^2-1)/d(n^2+2)$, values corresponding to the molecular refractivity as calculated for transparent substances. If this is done for the simple sulphides, &c., and for members of the corresponding complex series, an additive relationship is found to hold for these MR values over a wide range of molecular weight and of reflectivities within the degree of approximation already made. A series of such results is given in table II.

A number of uses can be made of such calculations. In the first place they indicate a method by which the reflectivity of an ore-mineral can be computed. Secondly, the figures afford a useful check on the values of the density quoted in the literature. Two instances of this may be briefly noted. In the preliminary calculations, a density of 6·53 was assumed for naumannite (Shannon [1]), giving an MR value for naumannite higher than that for hessite, and a computed value for eukairite much higher than the calculated value. Shannon's determination of the density, admittedly made on contaminated material, is certainly too low. For klaprothite a value of 4·6 is universally quoted in the literature, based on an early determination by Petersen; this gives widely discordant results and should probably read 6·4, the value obtained by calculating backwards from the computed MR value. It has proved impossible to obtain from the only authentic locality sufficient material in a pure state for a specific gravity determination, but a sample prepared artificially gave a value of 6·3. For the related sulphide wittichenite, the values quoted range from 4·3 to 6·7, and the value obtained by calculation is 6·2. A review of the densities of the sulphides, based on these and other considerations, is in progress.

[1] F. E. Wright, Proc. Amer. Phil. Soc., 1919, vol. 58, p. 426. [M.A. 1–198.]
[2] E. P. T. Tyndall, Physical Rev., 1923, vol. 21, p. 180.
[3] J. Orcel, loc. cit., p. 302.
[4] E. V. Shannon, Amer. Journ. Sci., 1920, ser. 4, vol. 50, p. 391. [M.A. 1–144.]

TABLE II. Comparison of the MR values of complex sulphides, calculated from the reflectivities, with those computed from the MR values of the simple sulphides.

Mineral.	Density.	Reflectivity.	MR values. Calculated.	Computed.
Aikinite	6·8	37·5	141	141
Alaskaite	6·2	40	104	95
Andorite	5·3	27·5	246	257
Aramayoite	5·6	31	83	86
Beegerite	7·2	36	224	232
Boulangerite... ...	6·3	34·5	137	140
Bournonite	5·8	30	242	253
Chalcostibite ...	5·0	35	82	77
Dufrenoysite ...	5·5	28	100	106
Emplectite	6·5	35	108	86
Eukairite	7·6	27	49	53
Freieslebenite ...	6·0	30·5	250	253
Geocronite	6·4	30·5	188	195
Jordanite	6·4	32·5	175	160
Klaprothite	6·4 ?	34	190	191
Lillianite	7·0	45	140	150
Livingstonite ...	4·8	32·5	150	138
Meneghinite	6·4	35	166	167
Miargyrite	5·3	29	86	86
Pearceite	6·1	25·5	296	298
Plagionite	5·5	29	358	370
Plumosite	5·6	32	116	113
Polybasite	6·2	25·5	302	305
Proustite	5·5	21	121	132
Pyrargyrite	5·8	27	140	141
Rathite	5·3	33	183	186
Sëmseyite	5·9	35	488	480
Stephanite	6·2	27·5	190	195
Stromeyerite ...	6·2	26	48	46
Stylotypite	5·1	24·5	114	114
Tennantite	4·7	24	134	124
Tetrahedrite... ...	4·8	24	145	133
Wittichenite... ...	5·9	29·5	129	124
Zinckenite	5·3	33	88	86

A final and more speculative extension of these calculations may be briefly indicated. The refractivities calculated from the Lorenz-Lorentz equation should be strictly additive in any system in which the electron-shells of the constituents remain unaffected, and any departure from strict additivity is to be interpreted as a deformation of at least one of the constituents (Fajans and Joos [1]). Present interest in the molecular refractivities of transparent ionic substances

[1] K. Fajans and G. Joos, Zeits. Physik, 1924, vol. 23, p. 5.

lies in tracing such departures. The approximations introduced above will obscure any similar variations, but it seems worth while to note that, pursuing the conception of strict additivity, the *MR* values derived above are comparable with those obtained for anion and kation in the study of transparent ionic substances. Thus, taking values of *MR* Pb 9·93, Zn 1·70, Cd 4·46 (Wasastjerna [1]), values for *S* are obtained from 17·7 to 12·1, for Se 20·1, and for Te 28·3. Haase [2] derives from a study of the compounds of S, Se, and Te with the alkaline earths values for S 17·20 to 11·96, for Se 20·71 to 14·89, and for Te 27·90 to 23·39.

[1] J. A. Wasastjerna, Soc. Sci. Fennica Comm. Phys.-Math., 1923, vol. 1, no. 37.
[2] M. Haase, Zeits. Krist., 1927, vol. 65, p. 581. [M.A. 3–421.]

Clay minerals and bauxitic minerals. A review and classification based on a statistical method.

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[Read June 15, 1933.]

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I. Introduction.

THE hydro-aluminous silicates form a well-defined natural group of minerals commonly known as clay minerals. According to their chemical composition they cover a wide range varying from substances rich in alumina, and thus approaching the bauxite group, to substances rich in silica. They vary greatly in their water content, and contain other constituents in addition to water, alumina, and silica—so-called impurities. Clay minerals always occur in the form of fine aggregates usually composed of minute crystals with a perfect basal cleavage, often ultra-microscopic in size (colloform and colloidal).

The absence of well-defined crystals of appreciable size makes the mineralogical and chemical investigations extremely difficult, since the separation of pure material is often impossible. The majority of published chemical analyses show a 'bulk' composition, i.e. composition of a mixture including the impurities. But the impurities cannot altogether be ignored, since they may throw some light on the nature of parent minerals or the composition of the intermediate products.

As to the nomenclature of these minerals, especially those belonging to the clay mineral group, we find ourselves in a maze of names, most of them quite obsolete and often applied to mixtures and not to definite stoicheiometric compounds. Unfortunately the number of names seems to increase from year to year, thus introducing additional complications to the understanding of these minerals.

An attempt to classify clay minerals on a triangular diagram has been made by E. T. Wherry,[1] but only theoretical formulae of these minerals were used. As minerals of the clay and bauxite groups show such a great variation in composition and are difficult to study in a purified form, the present writer has decided to apply statistical methods to their study. The degree of accuracy and reliability of any statistical study depends on the following conditions: (1) the accuracy of the primary data, (2) the number of cases, and (3) the number of variables.

With the object of procuring as many cases as possible, it was decided to include all analyses in which the amount of clay constituents (H_2O, Al_2O_3, SiO_2) was sufficiently high to guarantee that the greater part of the substance analysed was composed of hydrous aluminium silicate. To introduce a hypercritical attitude as to the quality of the material and the analysis would reduce the number of available analyses to a very small figure. Certainly the initial inaccuracy of the data is by no means removed by statistical computation, but provided that sufficient data are given, statistical methods may bring out, in the form of a significant distribution, many characters implicit in individual data. Persistent errors, if asymmetrical, can, in many cases, be traced by statistical methods, while distributive or symmetrical errors will only produce a wider deviation of distribution. Selection of primary data is even more dangerous than errors introduced through indiscriminate collection of them. For this reason a great number of analyses have been collected from all available sources, far too numerous to be quoted in this paper.

As already mentioned, the question of 'impurities' is rather important. The 'impurities' may be as follows: (1) mechanical admixtures of minerals other than the one presumed to have been isolated for analysis, (2) adsorbed substances, and (3) substances in chemical combination with a given mineral. As it is quite impossible to ascertain their nature and distribution, it has been decided to reject from the analyses all oxides, other than H_2O, Al_2O_3, and SiO_2,

[1] E. T. Wherry, Amer. Min., 1925, vol. 10, p. 140.

and to recalculate these latter oxides to 100 %. In order to find the true ratios of these oxides in the pure clay mineral, it is clear that one should also remove from the analysis any silica, alumina, and water which was in combination in the impurities. But there is no evidence which would enable one to do this; the correction would be small, and the errors introduced by its neglect would probably be of distributive nature.

All analyses showing less than 10 % of impurities have been included. Analyses which showed a marked divergence from the total 100 % were rejected. The calculated frequency curve for 'totals' shows a typical symmetrical modal distribution curve about 100 %. The mean difference between the average total and the average sum of clay constituents, i.e. the average of impurities is about 5 %. The total number of analyses included is as follows:

for H_2O–Al_2O_3–SiO_2 system . . .	689
for H_2O–Al_2O_3–Fe_2O_3 system . . .	320

All analyses, after being recalculated in terms of the principal variable constituents (calculated to 100 %), have been plotted on triangular diagrams. As the variables have been thus reduced to a small number (three) it is easy to trace the relationships between different minerals. The plotting on the triangular diagrams show three characteristic forms of distribution: (1) clusters, (2) trend lines, and (3) disperse fields. These forms of distribution can easily be observed in the two triangular diagrams presented in this paper (figs. 1 and 7).

The molecular ratios between the three principal constituents were used in the construction of frequency curves. For a clay mineral we have the formula $m H_2O.n Al_2O_3.p SiO_2$, in which the three ratios are $m : n$, $p : n$, and $m : p$. Taking $m : n = h$ and $p : n = s$, we get $h H_2O.Al_2O_3.s SiO_2$. For the minerals of the bauxite group only one ratio $H_2O : Al_2O_3$ has been used.

II. Clay Minerals.

The analyses of these minerals are plotted on the triangular diagram H_2O–Al_2O_3–SiO_2 (fig. 1). The diagram representing lines of constant ratios and the position of minerals is shown in fig. 2, and the frequency diagrams in figs. 3, 5, and 6. Besides the clay minerals the triangular diagram includes a few minerals belonging to the group of opals and some hydrated products of sillimanite,

andalusite, &c. The ratio $SiO_2 : Al_2O_3$ (s) is used as a basis of classification and the minerals are classified in broad groups according to this ratio, while their precise position in the field is determined by the ratio $H_2O : Al_2O_3$ (h).

1. *Fuller's earth group* (s from 4·5 to 9).

All members of this group are colloidal or colloform clay-like minerals of highly variable composition. This especially is shown in their water content, which in its greater part is colloidally adsorbed water. Many of them also possess a high degree of adsorption for dyes and fats. When dry they adhere to the tongue.

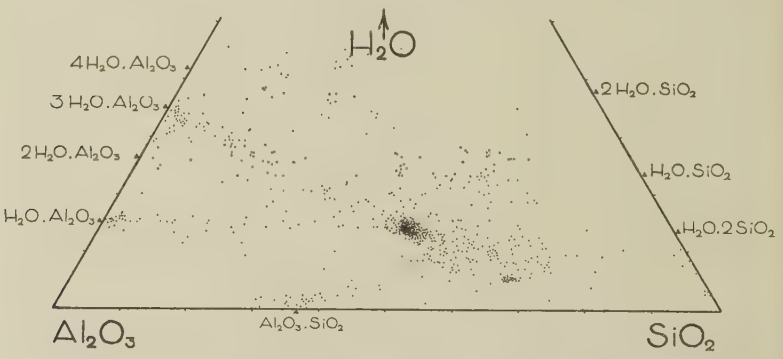

Fig. 1. The analyses of clay and bauxitic minerals plotted on the triangular diagram H_2O–Al_2O_3–SiO_2.

Besides the normal clay constituents, many of these minerals contain a certain proportion of alkalis and alkaline earths. These may be part of the mineral molecule or adsorbed material. In this respect they present an analogy to the zeolites. Owing to these loosely bound alkalis some of the fuller's earths (e.g. the so-called 'kil' in the Crimea) can be used as a substitute for soap.

Members of this group, containing considerable amounts of R_2O and RO oxides, cannot, strictly speaking, be classed with the clay minerals, if we define them as pure hydrous aluminium silicates. On the other hand, some 'bulk' analyses of bentonitic clays show the ratios s and h high enough ($h = 9·9$, $s = 7·25$) to place them in this division. Bentonites are also characterized by high adsorptive properties. Saponite is definitely excluded from this group. It belongs to the group of chlorites, although some saponites with a lower MgO

content may form intermediate members connecting the chlorite group with that of fuller's earth.

Looking at the distribution of dots on the triangular diagram, one sees no evidence for the existence of any stoicheiometric compounds. Even if they do exist they are probably masked by the total effect of colloidal mixtures. The estimation of water is a difficult problem and very few analyses give a satisfactory answer as to its nature. Some minerals such as termierite were given formulae from the analysis of samples saturated with water ($18H_2O.Al_2O_3.6SiO_2$).

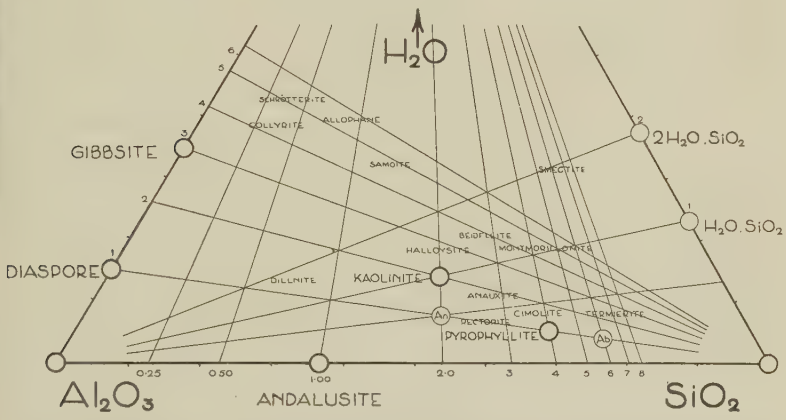

FIG. 2. The triangular diagram H_2O–Al_2O_3–SiO_2 with lines of equal ratios and mineral names. [An and Ab the alumino-silicic acids corresponding to anorthite and albite.]

By recalculating analyses in terms of three components we can represent them on the triangular diagram and draw a generalized scheme of their distribution; we must remember, however, that the names do not necessarily refer to definite chemical compounds, but more often to mixtures. According to the decreasing average ratio h, the minerals of this group can be arranged in the following way:

Malthacite	...	... $h = 19$	(probably saturated sample)
Smectite	...	... $h = 12$	
Ehrenbergite	...	... $h = 6{\cdot}5$	
Termierite	...	... $h = 2{\cdot}5$	(dried at 110° C.)

It is quite possible that if these substances were analysed by uniform methods and the water given out at different temperatures accurately determined, their classification would be altogether different.

2. *Pyrophyllite group* (s from 3·5 to 4·5).

In this group we find a definite small cluster on the triangular diagram and significant modal peaks on frequency curves (figs. 1, 3, 5, 6), where we find $h = 1$ (masked by the mode of diaspore) and $s = 4$. This, in conjunction with the mineralogical evidence, proves that the substance of composition $H_2O.Al_2O_3.4SiO_2$ (pyrophyllite) is a definite crystalline compound.

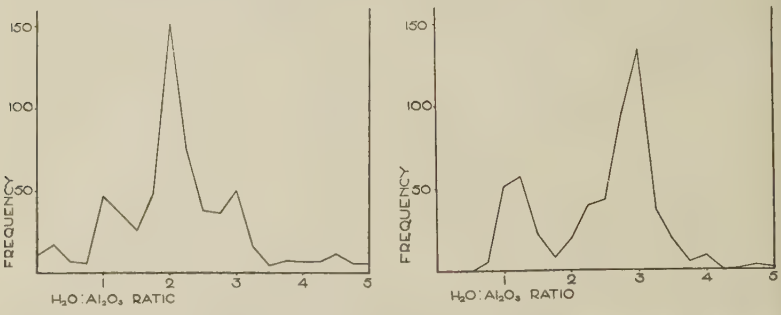

Fig. 3. The frequency diagram for $H_2O : Al_2O_3$ ratio in clay minerals. Modes: 0·25 small, probably accidental; 1·00 medium, aluminium monohydrate and pyrophyllite superimposed; 2·00 kaolinite; 3·00 medium, aluminium trihydrate.

Fig. 4. The frequency diagram $H_2O : Al_2O_3$ ratio in bauxitic minerals. Modes: 1·25 (1·00) aluminium monohydrate; 3·00 aluminium trihydrate.

Pyrophyllite was first described by R. Hermann[1] from the Ural Mts., but, as shown by F. Loewinson-Lessing,[2] the original analysis of Hermann was made, not of a pure sample of pyrophyllite, but of a mixture of pyrophyllite and the so-called pseudopyrophyllite ($8H_2O.3RO.4Al_2O_3.9SiO_2$, where R is mainly Mg with a little Ca and Fe). According to Loewinson-Lessing pyrophyllite crystallizes in the orthorhombic system. It occurs as compact masses composed of minute flakes or fibres and also as a constituent mineral of shales and crystalline schists. It has a pearly lustre and white colour, but some varieties have a greenish tinge. Apparently it is widely distributed in nature. Several good analyses correspond closely to its theoretical formula. Pyrophyllite has been synthesized in an autoclave on several occasions.[3] A number of minerals described under

[1] R. Hermann, Ann. Phys. Chem. (Poggendorff), 1829, vol. 15, p. 592.

[2] F. Loewinson-Lessing, Journ. Russ. Min. Soc., 1895, vol. 33, p. 283.

[3] E. Baur, Zeits. Physikal. Chem., 1903, vol. 42, p. 567; and Zeits. Anorg. Chem., 1911, vol. 72, p. 119. M. Schlaepfer and P. Niggli, Zeits. Anorg. Chem., 1914, vol. 87, p. 52.

various names such as agalmatolite, pagodite, pyrauxite, gümbelite, westanite, biharite, neurolite, restormelite, &c., are substances more or less similar to pyrophyllite and apparently only differ in the state of aggregation and the presence of impurities.

Referring again to the triangular diagram, we see above the cluster of pyrophyllite an aureole of dots. They correspond to the analyses of various clay substances either amorphous or microcrystalline. The nearest region to pyrophyllite is occupied by the

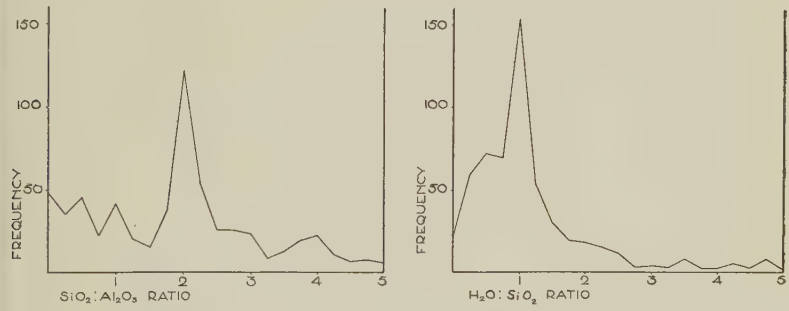

Fig. 5. The frequency diagram for $SiO_2 : Al_2O_3$ ratio in clay minerals. Modes: 0·00 medium, bauxitic minerals; 0·50 medium, schrötterite, collyrite (?); 1·00 medium, allophane; 2·00 large, kaolinite; 2 to 3 slope, probably mixture of kaolinite and anauxite; 4·00 small, pyrophyllite.

Fig. 6. The frequency diagram for $H_2O : SiO_2$ ratio for clay minerals. Modes: 1·00 large, kaolinite; the interval between 0·00 and 1·00 corresponds to a very dense disperse field of minerals of the region situated between pyrophyllite and kaolinite and the pyrophyllite ratio (0·25) is obscured; the mode of 0·50 is probably accidental; 1·00 to 3·00 slope, disperse field of minerals.

mineral called cimolite (including pelicanite, hunterite, keffekil, sphragidite, &c.). The *s*-ratio for these substances varies round about 4, and the *h*-ratio between 1 and 4, so that some of them can be considered to represent either hydrated pyrophyllite or pyrophyllite aggregates with adsorbed water.

The cimolite field passes imperceptibly upwards into the field of montmorillonite. Substances named montmorillonite, as well as others named confolensite, delanouite, stolpenite, erinite, severite, &c., show a great variety of composition (*h*-ratio varies from 2·4 to 7·4, *s*-ratio from 2·8 to 5·6). Nearly all analyses, however, fail to differentiate water given above and below 105° C., and as these minerals usually occur in aggregates of fine flakes or colloform

masses, the amount of adsorbed water must be considerable (in analyses where this determination was carried out, water below 105°C is usually half of the total water). In addition many minerals of this group contain a certain amount of RO and R_2O oxides. C. S. Ross and E. V. Shannon,[1] working on purified material derived from bentonitic clays, found the micaceous montmorillonite to approach in composition the theoretical formula $8H_2O.(Mg,Ca)O.Al_2O_3.5SiO_2$. As all the water of the analyses is included, this formula does not strictly speaking represent the composition of the crystalline phase. Excluding CaO and MgO, F. Heide[2] gave the theoretical formula of montmorillonite as $6H_2O.Al_2O_3.4SiO_2$. The same author found that montmorillonite has an X-ray spectrum similar to that of kaolinite. He suggested, therefore, that montmorillonite is not a distinct mineral, but a disperse system of silica hydrogels in a skeletal kaolinite lattice.

Considering the wide range of variation of analyses, the uncertain nature of constitutional water, and the absence of clusters on the triangular diagram, it is rather difficult to assign to montmorillonite a definite formula, but the following generalized formula may express its composition: $hH_2O.rRO.Al_2O_3.sSiO_2.aq$, where h varies from 2 to 4, r is usually about 1, s varies from 3 to 6 (higher values for s place the mineral in the group of fuller's earth, while values approaching 3 bring it into the field of beidellite).

So expressed, montmorillonite does not strictly speaking belong to the pure hydrous aluminium silicates. The dots on the triangular diagram are in this sense ambiguous, first because both constitutional and adsorbed water were included, secondly because of the presence of RO oxides in the analyses. A tetrahedral diagram constructed on our triangular diagram with $RO + R_2O$ occupying its apex would be more accurate for the representation of the analyses of these minerals.

3. *Anauxite group* (s from 2·5 to 3·5).

In this group we observe no definite clusters, but only a continuous disperse field. No definite stoicheiometric compounds are therefore to be deduced from the diagram. Most of the minerals belonging to this group appear as 'amorphous' aggregates, but some are

[1] C. S. Ross and E. V. Shannon, Journ. Amer. Ceramic Soc., 1926, vol. 9, p. 77.
[2] F. Heide, Chemie der Erde, 1927, vol. 3, p. 91.

definitely crystalline (micaceous habit). The substances of the low index of hydration give the following average ratios:

	h.	*s.*
Agalmatolite	1·0	3·0
Neurolite (in part) ...	1·1	2·7
Rectorite (in part) ...	1·2	2·5
Gümbelite	1·5	3·0

There is no evidence that any of these substances belong to a definite mineral species.

This field of low index hydration passes imperceptibly into the field occupied by a definite crystalline mineral anauxite (ionite), although there is no indication of a cluster on the diagram. The average formula of anauxite as given by V. T. Allen [1] is $2{\cdot}5H_2O.Al_2O_3.3SiO_2$, while C. S. Ross and P. F. Kerr [2] think that the formula $11H_2O.5Al_2O_3.14SiO_2$ corresponds to its average composition. My own recalculations of all published analyses of anauxite show a good approximation to both of these formulae, although the *h*-ratio is nearer to 2 than to 2·5. The average formula $2H_2O.Al_2O_3.3SiO_2$ (H_2O 11·30, Al_2O_3 32·05, SiO_2 56·65%), in which Al_2O_3 is sometimes replaced by Fe_2O_3, agrees well with the mean of the analyses of anauxite. According to C. S. Ross and W. F. Foshag [3] anauxite is monoclinic like kaolinite, while E. Dittler and J. E. Hibsch [4] are of the opinion that it is orthorhombic. But as shown by Ross and Kerr anauxite is similar to kaolinite in many respects—X-ray spectrum and optical properties, and it may be that anauxite is simply kaolinite with adsorbed silica, or it may be an intermediate product between kaolinite and pyrophyllite.

The next mineral above anauxite on the diagram (figs. 1 and 2) is beidellite, to which E. S. Larsen and E. T. Wherry [5] as well as C. S. Ross and E. V. Shannon [6] assign the formula $hH_2O.Al_2O_3.3SiO_2$, where *h* is approximately 4, and Al_2O_3 can be partly replaced by Fe_2O_3. It contains also a certain amount of CaO and MgO. The

[1] V. T. Allen, Amer. Min., 1925, vol. 13, p. 145. [Min. Abstr., vol. 3, p. 370.]

[2] C. S. Ross and P. F. Kerr, Prof. Paper, U.S. Geol. Survey, 1931, no. 165–E. [M.A. 5–359.]

[3] C. S. Ross and W. F. Foshag, Amer. Min., 1928, vol. 13, p. 153. [M.A. 3–488.]

[4] E. Dittler and J. E. Hibsch, Min. Petr. Mitt. (Tschermak), 1923, vol. 36, p. 85. [M.A. 2–306.]

[5] E. S. Larsen and E. T. Wherry, Journ. Washington Acad. Sci., 1925, vol. 15, p. 465. [M.A. 3–8.]

[6] C. S. Ross and E. V. Shannon, Journ. Washington Acad. Sci., 1925, vol. 15, p. 467. [M.A. 3–8.]

published analyses of beidellite show a variation of h from 3·0 to 5·5, and s from 1·8 to 3·9. As no definite clustering of dots is shown on the diagram, it is difficult to assign a definite formula to beidellite. According to E. S. Larsen beidellite is probably an orthorhombic mineral. It occurs in the form of minute micaceous flakes. Beidellite definitely belongs to the bentonite group and stands between the micaceous halloysite and montmorillonite.

4. *Kaolinite group* (s from 1·5 to 2·5).

Of the low hydration forms belonging to this group we have only a few indefinite substances, represented by one or two analyses in each case. They are as follows:

	h.		s.
Talcosite	0·5	...	2·0
Rectorite (in part) ...	1·0	...	2·0
Batchelorite	1·0	...	2·0

They are all scaly micaceous minerals. Some of them contain a small amount of alkalis and alkaline earths. The evidence afforded is not sufficient to assign them to any definite mineral species, as they may be low hydration forms of kaolinite or mixtures.

The principal mineral of this group is kaolinite. It gives the most prominent cluster of dots on the diagram, exactly corresponding to its theoretical formula $2H_2O.Al_2O_3.2SiO_2$. This cluster is slightly elliptical in shape with its long axis stretched along the line connecting gibbsite with pyrophyllite. On all the frequency curves kaolinite gives the most prominent modal peaks. About 200 analyses enter into the composition of the kaolinitic cluster, but many dots are superimposed and cannot be seen. The great number of analyses of kaolinitic clays is mainly due to their commercial importance, but this, in itself, indicates their widespread occurrence in nature. The analyses entering into the composition of the kaolinitic cluster correspond not only to substances bearing the name kaolinite or kaolin, but also to many others described under the names of nacrite, myeline, steinmark, pholerite, tuesite, indianaite, &c.

Kaolinite is a well-studied mineral and it is definitely established as a distinct mineral species. It occurs in the form of small monoclinic crystals with a perfect basal cleavage. As the recent work of C. S. Ross and P. F. Kerr [1] has shown, three distinct varieties of

[1] C. S. Ross and P. F. Kerr, Amer. Min., 1930, vol. 15, p. 34; and Journ. Sedimentary Petr., 1931, vol. 1, p. 55; loc. cit., 1931. [M.A. 4–247, 5–359.]

kaolin minerals must be distinguished, namely kaolinite, nacrite, and dickite. Their chemical composition and crystalline system are the same and they differ from one another in their optical properties and X-ray spectra. To these three varieties we may add, as suggested by J. W. Mellor,[1] a colloidal variety called clayite. It gives the same type of dehydration curve as kaolinite, namely a terrace at 500° C. and a hump at 900° C., not shown by any other clay mineral even halloysite. This suggests that clayite may be a colloid composed of crystalline molecules of kaolinite (disperse phase).

Above the kaolinitic cluster on the diagram there is a disperse field occupied by various colloform and microcrystalline substances. The principal mineral of this field is halloysite. Its average *s*-ratio is 2 the same as in kaolinite, but the *h*-ratio varies between 2 and 5. On heating, half of its water is given up at temperatures between 100° and 200° C., and one may suppose that this portion of its water is colloidally adsorbed; and if it were not for the fact that its heating curve does not show any definite terrace at 500° C., one would suggest that halloysite is a colloform variety of kaolinite. Pure amorphous forms of halloysite may perhaps be considered analogous to clayite but with crystalline molecules of different structure. On the other hand, micaceous halloysite, containing a certain amount of RO and R_2O oxides, is now grouped together with the minerals of bentonitic clays.

Other substances under the names of galapektite, gummite, lenzine, severite, indianaite, samoite, &c., find their place in the same field as halloysite. All these names as applied to distinct mineral species are hardly justified. The mineral newtonite has no place among the clay minerals. The original analysis suggested the formula $5H_2O.Al_2O_3.2SiO_2$, but a new analysis of the same substance by W. F. Foshag[2] has shown that it contains 34·92 % of SO_3 and therefore is nearer to alunite in its composition. The mineral named kochite[3] has been described of the composition $2{\cdot}5H_2O.Al_2O_3.1{\cdot}5SiO_2$ and apparently crystallizing in the cubic system. As no clay mineral has up to the present ever been found to crystallize in the cubic system, the question as to the existence of kochite as a distinct

[1] J. W. Mellor, Trans. Ceramic Soc., 1917, vol. 16, p. 73.

[2] W. F. Foshag, Amer. Min., 1926, vol. 11, p. 33. [M.A. 3–351.]

[3] S. Kôzu, K. Seto, and K. Kinoshita, Journ. Geol. Soc. Tokyo, 1922, vol. 29, pp. 1, 148. [M.A. 2–51, 521.]

mineral species must be left open until it is confirmed by further research.

We have now before us the difficult question as to the position to be occupied by the mineral named leverrierite in our scheme and even if this name should be retained at all. Leverrierite was first described by P. Termier.[1] It occurs in the form of 'rouleaux' and hexagonal flakes similar to kaolinite. In the original analyses the s-ratio varies from 2·3 to 3·7 and the h-ratio from 1·3 to 4·5. In addition, some analyses show considerable amounts of MgO and CaO, and this fact is supported by recent work of E. S. Larsen and E. T. Wherry [2] and of E. V. Shannon.[3] Considering all the analyses published, leverrierite shows a great variability of composition. C. S. Corbett,[4] following Larsen and Wherry, placed leverrierite in the group embracing such various minerals as batchelorite, rectorite, delanouite, and pyrophyllite, and gave the theoretical formula for the minerals of this group as $2{\cdot}5H_2O.Al_2O_3.2SiO_2$. This formula can apply to some of the analyses of leverrierite, but it certainly does not correspond to pyrophyllite, rectorite, &c. In a later paper Larsen and Wherry (loc. cit., 1925) isolated some of the minerals previously described under the name of leverrierite and proposed a new name of beidellite for minerals of $s = 3$, restricting the name of leverrierite for minerals of $s = 2$ ($h = 4$). Analyses of purified samples of beidellite by Ross and Shannon (1925) show an approximation to the proposed formula and also emphasize the fact that there is always some MgO and CaO present. In certain samples Fe_2O_3 partly replaces Al_2O_3, and it was suggested that beidellite represents an isomorphous mixture composed of $nH_2O.Al_2O_3.3SiO_2$ and $nH_2O.Fe_2O_3.3SiO_2$. Ross and Shannon (loc. cit., 1926) and also Ross and Kerr (1930), in their review of the minerals of bentonitic clays, omit leverrierite altogether and place micaceous halloysite in the division corresponding to $s = 2$. C. S. Ross, in a private communication to the present author, suggests that the name 'leverrierite' should be dropped, since this mineral, as first described, is a member of the kaolinite family. This is no doubt true, if we consider the analyses poor in RO and R_2O oxides, but some of the

[1] P. Termier, Compt. Rend. Acad. Sci. Paris, 1889, vol. 108, p. 1071.

[2] E. S. Larsen and E. T. Wherry, Journ. Washington Acad. Sci., 1917, vol. 7, p. 208. [M.A. 2–133.]

[3] E. V. Shannon, Proc. U.S. Nat. Mus., 1922, vol. 62, art. 15. [M.A. 2–134.]

[4] C. S. Corbett, Amer. Journ. Sci., 1925, ser. 5, vol. 10, p. 247. [M.A. 3–382.]

original analyses of leverrierite contain as much as 6·80 % CaO, besides some MgO and K_2O. This suggests that minerals of the composition $nH_2O.mRO.Al_2O_3.2SiO_2$ should find their place in the group of bentonitic clays and be given a distinctive name. Provisionally the name of micaceous halloysite may be accepted.

The group of bentonitic clays must therefore be considered as distinct from the group of pure clay minerals, although it is connected with the latter group by numerous intermediate members. The following generalized formula may be proposed as expressing the composition of all the members of the group of bentonitic clays: $hH_2O.RO.Al_2O_3.sSiO_2$; and the individual members of this series are as follows:

1.	Micaceous halloysite	$s = 2$
2.	Beidellite	$s = 3$
3.	Montmorillonite	s from 4 to 6
4.	?	s from 6 to 9

It would be unwise to identify the last unnamed member of this series with saponite, for saponite, with its high percentage of RO oxides, is obviously a member of the group of chlorites.

The minerals of the bentonitic clays are not only related to pure clay minerals, but also to the group of micas. The generalized formula proposed for the group of bentonitic clays can apply with certain modifications also to the group of micas. To get an idea of the frequency distribution of the s-ratios in micas, I have calculated and plotted on a frequency diagram (not given here) this ratio for 479 analyses of muscovite, biotite, lepidolite, and zinnwaldite. The general variation curve shows a great amount of dispersion (from 1 to 8) and a marked asymmetry with a maximum density between 2 and 4, and a gradually decreasing density from 4 to 8. This curve, as regard dispersion and distribution of densities (excepting the modal peaks), corresponds to the frequency curve for clay minerals (from 2 upwards) (fig. 5). The main differences between the clay minerals, bentonitic minerals, and the micas are as follows:

Clay minerals ...	$RO = 0$	$R_2O = 0$
Bentonitic minerals	$H_2O > RO$	R_2O small amount
Micas	$H_2O < RO$	R_2O considerable amount

(Signs $<$ and $>$ refer to weight percentages.)

Between the micas and the bentonitic group one can place the group of hydromicas, a group as yet only vaguely defined.

On the triangular diagram (figs. 1 and 2) the minerals of the bentonitic group are alined more or less parallel to and above the series of pure clay minerals (kaolinite, anauxite, pyrophyllite, termierite). Their actual position on the diagram is mainly due to the fact that on recalculating their analyses, in the majority of cases, the total amount of water had to be taken into account. Allowing 50 % or even more of the total water to be adsorbed moisture, the whole group can be lowered down so as to coincide with the region of pure clay minerals.

It is also of interest to notice that if in the formulae of micas and felspars the RO and R_2O oxides be replaced by equivalent molecules of water, the resulting alumino-silicic acids when plotted on the triangular diagram occupy a region almost coinciding with that of the clay minerals.

5. *Bauxitic clay group* (*s* from 0·0 to 1·5).

This group, embracing almost the whole of the left half of the triangular diagram, is mainly composed of two trend-lines of dots, stretching from the region of kaolinite towards gibbsite and diaspore respectively. As there is no reason to suppose that these minerals are capable of forming isomorphous mixtures, we must presume that the analyses represented by dots situated along these trend-lines belong to mixtures of kaolinite with the two bauxitic minerals. These mixtures are commonly known under the name of bauxitic clays. However, there are also dots situated outside the two trend-lines. Some of them refer to substances which were given distinct names, which are as follows:

	s (average).	*h*.
Dillnite	0·75 ...	0·2 – 1·7
Samoite	1·50 ...	4·5 – 5·5
Allophane ...	1·00 ...	4·0 – 10·0
Collyrite	0·50 ...	4·0 – 6·0
Schrötterite ...	0·40 ...	3·0 – 5·5

Only one of these minerals (dillnite) lies on the line connecting kaolinite and diaspore and probably represents one of the many possible mixtures of these two minerals. The remaining minerals are difficult to place. The frequency curve for the *s*-ratio (fig. 5) gives two small modes for the values of $s = 0{\cdot}5$ and $s = 1{\cdot}0$. If these two modes are not accidental (due to the magnitude of the selected interval for the lower values of *s*-ratio), they may refer to collyrite

and allophane respectively. In any case the number of analyses of these substances is not sufficient to draw any conclusions from the statistical data. All these minerals are found in colloidal or colloform state and only X-ray analysis can solve this problem. It may be, that some, if not all, of these minerals are hydrated mixtures of kaolinite and gibbsite. For example, a mixture of kaolinite and gibbsite in equal molecular proportions would give allophane, i.e. $3H_2O.Al_2O_3 + 2H_2O.Al_2O_3.2SiO_2 = 2(2{\cdot}5H_2O.Al_2O_3.SiO_2)$. Actual analyses of allophane show a higher proportion of water than indicated in the last formula, but this may be due to the fact that colloidal mixtures are apt to contain much adsorbed water.

III. Bauxitic Minerals.

Pure alumina hydrates occur in nature only in exceptional cases. Usually they are found mixed with clay minerals and iron oxides (the two principal ingredients). The classification of bauxites are numerous. In a recent monograph on the bauxites of southern France, J. de Lapparent[1] gives a detailed chemical classification of bauxites, according to the prevalence of the two additional components Fe_2O_3 and SiO_2, such as megaferric, ferric, microferric, megaluminic, aluminic, siliceous, and megasiliceous bauxites. On the other hand, A. Lacroix[2] and L. L. Fermor[3] accept the name of laterite as a generic term for all the rocks rich in alumina hydrates, with a further subdivision into silicic laterites, lateritic clays, &c. However, following a usage accepted by many writers, it seems advisable to apply the term bauxite to rocks mainly composed of alumina hydrates and restrict the term laterite to ferruginous bauxites. The following simplified scheme of classification is therefore proposed :

Rocks.		Composition.
Clays		Clay minerals
Bauxites	Bauxitic clays (siliceous bauxites)	Mixture of clay and bauxitic minerals
	Pure bauxites	Bauxitic minerals
	Laterites (ferruginous bauxites)	Mixture of bauxitic and ferric minerals
Iron-ores		Ferric oxides and hydrates

[1] J. de Lapparent, Les bauxites de la France méridionale. Mém. Carte Géol. France, Paris, 1930.

[2] A. Lacroix, Minéralogie de Madagascar. Paris, 1923, vol. 3.

[3] L. L. Fermor, Geol. Mag., 1915. dec. 6, vol. 2, pp. 28, 77, 123.

It is obvious that there are no hard-and-fast demarcations between these divisions, as even ordinary clays, as shown by M. G. Edwards,[1] contain certain amounts of alumina hydrates, while the majority of bauxites contain clay minerals (the average of 16 analyses of French bauxites, as recalculated by J. de Lapparent, gives the following figures: boehmite and diaspore 54·05, gibbsite 16·35, kaolinite 29·60 %). The distribution of dots along the trend-lines on the two triangular diagrams (figs. 1 and 7) seem to support the idea of a perfect gradation between the clays, the bauxites, and the iron-ores.

In the present paper all the siliceous bauxites have been included in the triangular diagram $H_2O - Al_2O_3 - SiO_2$ (fig. 1); while the ferruginous bauxites (to almost a pure iron-ore), to the total number of 320, have been included in the triangular diagram H_2O–Al_2O_3–Fe_2O_3 (fig. 7). Both diagrams show a distinct clustering of points at the positions of the mono- and trihydrates of alumina and two well-defined trend-lines stretching from these points towards kaolinite in one case, and towards Fe_2O_3 and $H_2O.Fe_2O_3$ in the other.

The frequency curve of the ratio $H_2O : Al_2O_3$ in the clay minerals (fig. 3) already suggests the presence of substances of the ratio one and three. But as these two modes may have been produced by some of the clay minerals, the ratios $H_2O : Al_2O_3$ for all bauxites (total 561) were calculated and plotted on a separate diagram (fig. 4). This frequency diagram brings out the existing relationship very clearly. Two prominent modes are present, namely ratio 1·25 and ratio 3. The ratio of 1·25 is probably a shifted mode of ratio 1, due to the fact that alumina monohydrate often occurs in a colloidal form and so is more apt to retain adsorbed water, or it may be due to the influence exercised by the presence of ferric monohydrate. The second mode corresponds exactly to alumina trihydrate.

The distribution about these modes is unsymmetrical, i.e. it has a greater density towards the minimum situated between them. The whole character of the frequency curve suggests that we are dealing here with a mixture of alumina monohydrate and alumina trihydrate; while the ratio of the ordinates of the two modes suggests that in the assemblage of analyses considered these two substances are present in the proportion of 1 to 2·3 respectively.

The ratio 2 falls near the minimum of the curve, and thus the statistical evidence suggests that the compound $2H_2O.Al_2O_3$ has no real existence. Actually a compound of this composition has never

[1] M. G. Edwards, Econ. Geol., 1914, vol. 9, p. 112.

been observed, either in nature or in laboratory. The original substance analysed by P. Berthier[1] in 1821, and later called 'beauxite' (A. Dufrénoy, 1847), is not a mineral but a rock, containing, in addition to alumina hydrates, over 27 % of Fe_2O_3, and the approximation of its ratio to 2 is purely a matter of accident. (In the frequency diagram, fig. 4, there are 20 analyses of bauxites, out of the total 561, in which this ratio is equal to two.) In rocks com-

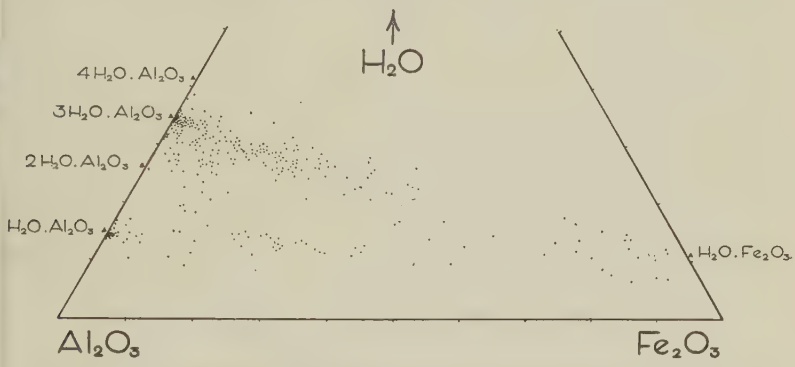

FIG. 7. The analyses of bauxites and laterites plotted on the triangular diagram H_2O–Al_2O_3–Fe_2O_3.

posed mainly of a mixture of alumina mono- and trihydrates, there is always a possibility of getting a mean proportion of the two. All works which attempt to prove the existence of a dihydrate of alumina from the consideration of a few individual analyses, such as a recent paper by T. V. M. Rao,[2] are based on this fallacy. To achieve the rank of a mineral species a given substance must be either capable of isolation in its pure crystalline (or amorphous) form, or of being produced in the laboratory. In the case of alumina dihydrate this proof of mineral status has never been achieved. The statistical evidence based on all available analyses, taken in conjunction with the negative evidence previously recorded by numerous observers, definitely points to the fact that alumina dihydrate, commonly called 'bauxite' ($2H_2O.Al_2O_3$), does not exist as a mineral species. Therefore the name 'bauxite' as originally applied to the rock analysed by Berthier must be used as a generic term for rocks rich in alumina hydrates.

[1] P. Berthier, Ann. des Mines, 1821, vol. 6, p. 531.
[2] T. V. M. Rao, Min. Mag., 1928, vol. 21, p. 407.

The frequency diagram (fig. 4) seems also to indicate that the gibbsitic bauxites are more abundant in nature than the diasporic bauxites. Apparently different regions have different proportions of these minerals in bauxites. Indian bauxites, for example, are mainly gibbsitic, while in the French bauxites, boehmite is the dominant constituent. Although only two hydrates of alumina are suggested by the present statistical study, there exist several polymorphous forms and isomers of each. The following is the list of bauxitic minerals drawn in accordance with the recent data :

Alumina monohydrate:	
Diaspore, Boehmite	Orthorhombic isomers
Kayserite, Tanatarite	Monoclinic isomers (?)
Sporogelite	Colloidal
Alumina trihydrate:	
Gibbsite (hydrargillite), Bayerite	Monoclinic isomers
Alumina tetrahydrate:	
Scaly variety [1]	Isotropic
Shanyavskite	Colloidal

The right-hand corner of the triangular diagram (fig. 7) is occupied by a few aluminous iron-ores. Apparently they indicate the presence of ferric monohydrate and ferric oxide. Ferric monohydrate occurs in two dimorphous forms, both crystallizing in the orthorhombic system, namely goethite and lepidocrocite (ruby-mica). J. Böhm [2] found that goethite gave an X-ray diffraction pattern similar to that of diaspore, while that of lepidocrocite was similar to that of boehmite. J. de Lapparent records the occurrence in bauxites of goethite and haematite only, with the addition of limonite as a product of weathering. These minerals, however, seldom occur as mineral grains, they are generally found closely mixed with alumina hydrates in a paste which de Lapparent calls 'gel alumino-ferrique'. The evidence derived from the study of the analyses plotted on the triangular diagram (fig. 7) points to the same conclusion. The laterites (ferruginous bauxites) are mechanical mixtures of alumina monohydrate, alumina trihydrate, ferric monohydrate, and ferric oxide. There is no indication of isomorphism between $H_2O.Al_2O_3$

[1] P. Neogi and A. K. Mitra, Journ. Chem. Soc. London, 1927, part 1, p. 1222.
[2] J. Böhm, Zeits. Anorg. Chem., 1925, vol. 149, p. 311. [M.A. 3-430.]

and $3H_2O.Al_2O_3$, but a solid solution between $H_2O.Fe_2O_3$ and Fe_2O_3 is possible (turite ?).

Bauxites, in addition to clay minerals and ferric hydroxides and oxides, contain minor constituents in varying amounts (manganese hydroxides, titanous hydroxides and oxides, zircon, tourmaline, &c.). Except for manganese hydroxides, which in certain bauxites attain considerable proportion, the other minor constituents play a very restricted role.

IV. Summary.

A statistical study of clay and bauxitic minerals, which consisted of plotting all available analyses of these minerals on two triangular diagrams (figs. 1 and 7) and constructing frequency curves for the cardinal ratios, led to a classification of these minerals on a purely chemical basis. The suggestion is also made that among substances claimed to be minerals we can select only a few as belonging to definite mineral species, and that the others are probably mixtures of these selected minerals, or their hydration products, or colloidal hydrates of variable composition. The distinct crystalline mineral species thus singled out are as follows :

Pyrophyllite	... $H_2O.Al_2O_3.4SiO_2$
Kaolinite and its isomers	... $2H_2O.Al_2O_3.2SiO_2$
Diaspore ,, ,, ,,	... $H_2O.Al_2O_3$
Gibbsite ,, ,, ,,	... $3H_2O.Al_2O_3$

Besides these minerals, other substances, such as termierite, anauxite, allophane, &c., are suggested as probable species, without, however, any clear statistical evidence. The bentonitic minerals, not belonging strictly to the pure hydrous aluminium silicates, are placed in a separate group.

In conclusion, I should like to thank Dr. G. Hickling and Mr. G. S. Mockler for reading the MS. of this paper and for their valuable suggestions.

Calculated chemical composition of substances represented by certain cardinal points on the triangular diagram H_2O–Al_2O_3–SiO_2 (fig. 2).

	H_2O.	Al_2O_3.	SiO_2.	
H_2O — $2SiO_2$ ...	13·00%	–	87·00%	... Di-silicic acid
H_2O - SiO_2 ...	23·05	—	76·95	... Meta-silicic acid
$2H_2O$ — SiO_2 ...	37·46	—	62·54	... Ortho-silicic acid
$2H_2O.Al_2O_3.6SiO_2$ ...	7·22	20·46	72·32	... (Termierite)
$8H_2O.Al_2O_3.6SiO_2$ ...	23·73	16·83	59·44	... (Termierite)
$12H_2O.Al_2O_3.6SiO_2$ ...	31·82	15·03	53·15	... —
$H_2O.Al_2O_3.4SiO_2$ ...	4·99	28·29	66·72	... Pyrophyllite
$2H_2O.Al_2O_3.4SiO_2$ ...	9·52	26·92	63·56	... (Cimolite)
$3H_2O.Al_2O_3.4SiO_2$ ...	13·61	25·72	60·67	... (Cimolite)
$H_2O.Al_2O_3.3SiO_2$ ...	5·99	33·92	60·09	... (Agalmatolite)
$2H_2O.Al_2O_3.3SiO_2$ ...	11·30	32·05	56·65	... Anauxite
$3H_2O.Al_2O_3.3SiO_2$ ...	16·07	30·31	53·62	... —
$H_2O.Al_2O_3.2SiO_2$ ...	7·48	42·42	50·10	... (Batchelorite)
$2H_2O.Al_2O_3.2SiO_2$ ...	13·93	39·48	46·59	... Kaolinite
$3H_2O.Al_2O_3.2SiO_2$ ...	19·54	36·92	43·54	... (Halloysite)
$H_2O.Al_2O_3.SiO_2$ ...	10·00	56·62	33·38	... —
$2H_2O.Al_2O_3.SiO_2$ ...	18·25	51·49	30·26	... —
$3H_2O.Al_2O_3.SiO_2$ ...	24·99	47·21	27·80	... —
$4H_2O.Al_2O_3.SiO_2$ ...	30·77	43·56	25·67	... (Allophane)
$5H_2O.Al_2O_3.SiO_2$ ...	35·72	40·45	23·83	... (Allophane)
$6H_2O.Al_2O_3.SiO_2$ ...	39·99	37·80	22·21	... (Allophane)
$8H_2O.2Al_2O_3.SiO_2$ ...	35·27	50·04	14·69	... (Collyrite)
$H_2O.Al_2O_3$ — ...	15·00	85·00	—	... Diaspore
$2H_2O.Al_2O_3$ ...	26·11	73·89	—	... —
$3H_2O.Al_2O_3$ ...	34·63	65·37	—	... Gibbsite
$4H_2O.Al_2O_3$ — ...	41·35	58·65	—	... —

PROCEEDINGS
OF THE
MINERALOGICAL SOCIETY

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., January 26, 1933, *at* 4.15 *p.m.*

Sir John S. Flett, F.R.S., President, in the Chair.

Mr. Arthur Richard Alderman, Mr. Harry Berman, Mr. Francis Ian Gregory Rawlins, and Prof. Karl Hermann Scheumann were provisionally elected Ordinary Members of the Society.

The resignation of Dr. L. T. Nel was received and accepted.

The Treasurer reported on the financial position of the Society and presented the audited accounts and Balance Sheet for the year ending December 31, 1932, which were accepted and passed (pp. l–liii).

GENERAL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., January 26, 1933, *at* 5.30 *p.m.*

Sir John S. Flett, F.R.S., President, in the Chair.

Thirty Members and thirteen Visitors were present.

The elections of Messrs. A. R. Alderman, H. Berman, F. I. G. Rawlins, and Prof. K. H. Scheumann as Ordinary Members of the Society were confirmed.

The following papers were then read :—

1. Meteoric irons and silica-glass from the meteorite craters of Henbury (Central Australia) and Wabar (Arabia): by Dr. L. J. Spencer (p. 387).

2. Garnet in the Dartmoor granite: its petrogenetic significance: by Dr. A. Brammall and Mr. S. Bracewell.

3. The identity of mottramite and psittacinite with cupriferous descloizite: by Mr. F. A. Bannister (p. 376).

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., March 23, 1933, *at* 4.30 *p.m.*

Sir JOHN S. FLETT, F.R.S., President, in the Chair.

The deaths were reported of Prof. Friedrich Rinne on March 12, 1933, an Honorary Member since 1926 ; and of Mr. Malcolm Roberts on January 13, 1933.

Dr. Gilbert Wilson was provisionally elected an Ordinary Member of the Society.

A letter was received from the XVIth Session of the International Geological Congress asking for delegates to be appointed, and it was decided to ask the President, Prof. C. Gilbert Cullis, and the General Secretary to act as representatives of the Society at the meeting to be held in Washington.

GENERAL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., March 23, 1933, *at* 5.30 *p.m.*

Sir JOHN S. FLETT, F.R.S., President, in the Chair.

Sixteen Members and two Visitors were present.

The election of Dr. Gilbert Wilson as an Ordinary Member of the Society was confirmed.

The following papers were then read :—

1. Biographical notices of mineralogists recently deceased (fifth series) : by Dr. L. J. Spencer (p. 337).

2. A possible source of error in the determination of symmetry from optical extinction-angles : by Mr. M. H. Hey (p. 367).

3. Studies on the zeolites. Part V. Mesolite : by Mr. M. H. Hey (with X-ray measurements by Mr. F. A. Bannister) (p. 421).

4. The dehydration of thomsonite : by Dr. A. E. Mourant (p. 371).

5. Note on the occurrence of piedmontite in quartz-muscovite-schist from the Shotover valley, western Otago, New Zealand : by Dr. F. J. Turner (p. 416).

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., June 15, 1933, *at* 4.15 *p.m.*

Sir John S. Flett, F.R.S., President, in the Chair.

The death of Prof. Victor Goldschmidt on May 10, 1933, was announced.

Dr. Stephen Robert Nockolds and Prof. Kunikatsu Seto were provisionally elected Ordinary Members of the Society.

The dates of meetings for 1934 were discussed, and it was decided that these should be held on the following Thursdays :—January 25, March 15, June 14, and November 8.

The list of Officers and Members of Council to be submitted to the Members for election at the next Anniversary Meeting was discussed. Sir John S. Flett and Prof. C. Gilbert Cullis were retiring from the offices of President and Vice-President respectively, and the following Ordinary Members of Council are due to retire: Dr. A. F. Hallimond, Sir Albert E. Kitson, Prof. W. L. Bragg, and Prof. H. H. Read. The President proposed that Sir Thomas H. Holland be asked to stand for election as President, and Sir William H. Bragg as Vice-President. The following were proposed as ordinary Members of Council: previous members, Mr. T. Crook and Dr. W. F. P. McLintock; new members, Dr. A. K. Wells and Mr. L. R. Wager.

Vacancies in the list of Honorary Members were discussed, and a voting list was drawn up.

Amongst letters received was one from the Geological Society of London, asking for a contribution towards a plaque to be placed on the house at 14 Buckingham Street, London, W. 1, in commemoration of William Hyde Wollaston, F.R.S., who lived there from 1801 to 1825. The Treasurer proposed a donation of two guineas, which was agreed.

The Secretary reported that a very successful excursion was made to Swallowfield Park to see Mr. Arthur Russell's collection of British minerals. This was attended by twenty-four members and guests, and the thanks of the Society were conveyed to Sir Charles and Mr. Arthur Russell.

GENERAL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., June 15, 1933, *at* 5.30 *p.m.*

Sir JOHN S. FLETT, F.R.S., President, in the Chair.

Thirty Members and three Visitors were present.

The elections of Dr. S. R. Nockolds and Prof K. Seto as Ordinary Members of the Society were confirmed.

The following papers were then read:—

1. Minute spheres of nickel-iron in the silica-glass from the meteorite craters at Wabar, Arabia: by Dr. L. J. Spencer (p. 387).

2. Portlandite, a new mineral from Scawt Hill, Co. Antrim: by Prof. C. E. Tilley (p. 419).

3. Clay minerals and bauxite minerals. A review and classification based on statistical methods: by Mr. S. I. Tomkeieff (p. 463).

4. Studies on the zeolites. Part VI. Edingtonite: by Mr. M. H. Hey (with X-ray measurements by Mr. F. A. Bannister) (p. 483).

5. On the accuracy of mineralogical measurements: by Mr. M. H. Hey (p. 495).

6. On a new barium plagioclase felspar: by Dr. S. R. Nockolds and Dr. E. G. Zies (p. 448).

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., November 9, 1933, *at* 4 *p.m.*

Sir JOHN S. FLETT, F.R.S., President, in the Chair.

Mr. Archibald Thomas John Dollar, Lady Agnes Gibbs, Sir Robert Abbot Hadfield, Bart., Dr. Bernard Howard Knight, Dr. John Armstrong Smythe, and Mr. George Vaux were provisionally elected Ordinary Members of the Society.

The death of Dr. F. R. Van Horn on August 1, 1933, was announced.

The General Secretary read the draft Annual Report, which after amendment was approved.

Vacancies in the list of Honorary Members were considered. On a ballot being taken Prof. V. M. Goldschmidt and Prof. P. Niggli were selected subject to confirmation at the General Meeting.

GENERAL (ANNIVERSARY) MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., November 9, 1933, *at* 5.30 *p.m.*

Sir John S. Flett, F.R.S., and afterwards
Sir Thomas H. Holland, F.R.S., President, in the Chair.

Thirty-six Members and seven Visitors were present.

The chairman nominated Mr. A. Broughton Edge and Dr. W. Q. Kennedy to act as scrutineers of the voting-papers for the election of Officers and Council.

The elections of Mr. A. T. J. Dollar, Lady Agnes Gibbs, Sir Robert A. Hadfield, Bart., Dr. B. H. Knight. Dr. J. A. Smythe, and Mr. George Vaux as Ordinary Members of the Society were confirmed.

The elections of Prof. Victor Moritz Goldschmidt of Göttingen and Prof. Paul Niggli of Zürich as Honorary Members were confirmed.

The General Secretary then read the following:—

Annual Report of Council for 1933.

During the session 1932–33 four ordinary meetings have been held and twenty-three papers have been read. Four numbers (139–142) of the Mineralogical Magazine have been issued containing eighteen papers, occupying 214 pages and illustrated with 33 text-figures and 12 plates. These numbers also include 673 abstracts occupying 192 pages.

The Council regrets to announce the death of two Honorary Members. Prof. Friedrich Rinne and Prof. Victor Goldschmidt, and of two ordinary members, Mr. Malcolm Roberts and Dr. Frank Robertson Van Horn. Prof. Victor Goldschmidt, who was in his eighty-first year, was also an ordinary life-member of the Society.

One ordinary member has resigned and eleven have been elected, bringing the total membership on October 31, 1933, to 228, including 7 Honorary Members.

The accounts for the year ending December 31, 1932, showed an excess of assets (exclusive of the Library and stock of publications and Composition Fees Account) over liabilities of £1,146 10*s.* 10*d.* The value of the stock invested in the names of the Trustees on December 31, 1932, General Reserve £852 6*s.* 6*d.*, Composition Fees Account £962 16*s.* 3*d.*

The Society's Library has received during the year 147 parts of periodicals and 2 separate copies of papers. The facilities afforded by the Library seem to be little appreciated. Only 12 volumes have been borrowed during the year.

The Nomenclature Committee appointed on November 4, 1930, to co-operate with the Nomenclature Committee of the Mineralogical Society of America held one meeting in London on June 15. Prof. C. G. Cullis, Prof. O. T. Jones, and the General Secretary were co-opted as additional members. The President, the General Secretary, and Prof. Cullis were delegates of the Society to the 16th International Geological Congress held in Washington, D.C., in July, and during

the Congress attended a meeting of the Nomenclature Committee of the Mineralogical Society of America and achieved considerable progress towards agreement. They reported to the Nomenclature Committee of our Society at a meeting held on November 9 in London.

On May 20, 24 members and guests visited Swallowfield Park, near Reading, at the invitation of Sir Charles and Mr. Arthur Russell, and spent a most interesting afternoon inspecting Mr. Russell's unrivalled collection of British minerals.

Mr. S. E. Hollingworth proposed that the Annual Report be adopted. This was seconded by Dr. Gilbert Wilson and carried unanimously.

The scrutineers reported that 68 voting papers for the Officers and Council had been received and that the list nominated by the Council had been approved. The President declared these Officers and Ordinary Members of Council elected for the ensuing year :—

President. Sir Thomas H. Holland, K.C.S.I., K.C.I.E., D.Sc., F.R.S.

Vice-Presidents. Arthur Russell, M.B.E.
Sir William H. Bragg, O.M., K.B.E., M.A., D.Sc., F.R.S.

Treasurer. F. N. Ashcroft, M.A., F.G.S., F.C.S.

General Secretary. W. Campbell Smith, M.C., T.D., M.A., F.G.S.

Foreign Secretary. Prof. A. Hutchinson, O.B.E., M.A., Ph.D., F.R.S.

Editor of the Journal. Dr. L. J. Spencer, M.A., Sc.D., F.R.S.

Ordinary Members of Council.

F. A. Bannister, M.A.
Prof. C. E. Tilley, Ph.D., B.Sc., A.I.C., F.G.S.
Prof. P. G. H. Boswell, O.B.E. D.Sc., A.R.C.S., F.R.S.
Prof. H. L. Bowman, M.A., D.Sc., F.G.S.
Dr. L. Hawkes, D.Sc., F.G.S.
Dr. W. R. Jones, D.Sc., F.G.S.
Dr. F. C. Phillips, M.A., Ph.D., F.G.S.
J. B. Scrivenor, I.S.O., M.A., F.G.S.
T. Crook, A.R.C.S.I., F.G.S.
Dr. W. F. P. McLintock, D.Sc., F.G.S.
L. R. Wager. B.A., B.Sc., F.G.S.
Dr. A. K. Wells, D.Sc., F.G.S.

Sir John Flett then moved that Sir Thomas Holland take the chair.

A vote of thanks to Sir John Flett, retiring President, Prof. C. G. Cullis, retiring Vice-President, and to Sir Albert Kitson, Prof. W. L. Bragg, Dr. A. F. Hallimond, and Prof. H. H. Read, retiring Ordinary

Members of Council was proposed by Mr. M. H. Hey, seconded by Dr. A. W. Groves, and carried unanimously.

A vote of thanks to the Geological Society for the use of their rooms was proposed, seconded, and carried with acclamation.

The new President reminded the members that this year 1933 was the fiftieth anniversary of the amalgamation of the Crystallological Society and the Mineralogical Society, and that it was a subject for congratulation that the Society had among its members one, Sir Henry Miers, who was a member of the Crystallological Society, and one member of the Mineralogical Society, Prof. Henry Louis, elected in 1879 before the two societies came together.

Dr. Stanley Smith exhibited a model for demonstrating the relationship of the systems of symmetry.

The following papers were then read:—

1. Shower of meteoric stones in the neighbourhood of the village Kuznetzovo, West Siberia, on May 26, 1932: by Prof. P. L. Dravert (of Omsk), read by Dr. L. J. Spencer (p. 509).

2. Silica-glass from the Libyan Desert: by Mr. P. A. Clayton and Dr. L. J. Spencer (p. 501).

3. Fictitious occurrences of iron silicide (ferrosilicon): by Dr. L. J. Spencer.

4. Notes on the occurrence of wulfenite at Brandy Gill, Carrock Fell, Troutbeck, Cumberland; and of leadhillite at Drumruck mine, Gatehouse of Fleet, Kirkcudbrightshire: by Mr. Arthur Russell.

5. On the occurrence of harmotome at several new localities in the British Isles: by Mr. Arthur Russell.

6. Some relationships between the reflectivities of sulphide ore-minerals: by Dr. F. Coles Phillips (p. 458).

7. A critical list of the specific gravities of the sulphides and allied ore-minerals: by Dr. F. Coles Phillips.

8. Progressive metasomatism in the flint nodules of the Scawt Hill contact-zone: by Prof. C. E. Tilley and Mr. A. R. Alderman (p. 513).

MINERALOGICAL

ABSTRACT OF RECEIPTS AND PAYMENTS

Receipts.	£ s. d.	£ s. d.
By Balances brought forward from 1932—		
1. At Bankers:		
(*a*) Current Account	18 5 5	
(*b*) Deposit Account	185 0 0	
2. In Office	0 2 4	
		203 7 9
Entrance Fees		12 12 0
Annual Subscriptions—		
1. Current year	166 19 0	
2. Arrears	8 8 0	
3. Advance	8 11 0	
		183 18 0
Sale of Publications—		
1. By Publishers, April 1, 1932–March 31, 1933. Sales at subscription rate £222 0*s.* 0*d.* and other sales £29 18*s.* 0*d.*, less trade discount and commission £65 9*s.* 4*d.*, and distribution charges £14 0*s.* 7*d.*	172 8 1	
2. By Custodian of Stock, 1933. £15 19*s.* 0*d.*, less distribution charges £1 4*s.* 2*d.*, and cost of back numbers purchased £0 16*s.* 4*d.*	13 18 6	
		186 6 7
Advertisement Fees, £17 18*s.* 1*d.*, less commission £3 11*s.* 7*d.*		14 6 6
Interest on Investments as received—		
1. £640 3½% War Loan 1952, Inscribed Stock	22 8 0	
2. £105 4% Consolidated Loan 1957, Inscribed Stock	4 4 0	
3. £100 4% Funding Loan 1960–90, Inscribed Stock	4 0 0	
		30 12 0
Deposit Interest		1 13 7
Small Receipts		0 1 6
Transfers from other accounts—		
From Composition Fees Account, being Interest on Investments		34 2 6
		£667 0 5

GENERAL PUR-

SOCIETY

FOR THE YEAR ENDING DECEMBER 30, 1933

POSES ACCOUNT.

Payments.	£ s. d.	£ s. d.
To Printing and distributing the Mineralogical Magazine Nos. 140–143 inclusive (Oxford University Press)—		
1. Printing	266 18 6	
2. Illustrations	36 9 0	
3. Authors' Separate Copies	24 6 6	
4. Distribution Charges	12 12 0	
5. Postal Wrappers (renewal of stock)	2 4 6	
		342 10 6
Printing and distributing notices of Meetings and other annual miscellaneous printing		15 12 0
Miscellaneous Printing, &c. (not annual)—		
1. Treasurer's Notices	0 16 6	
2. Notices of Excursion, printing and postage	2 0 0	
		2 16 6
Expenses at Meetings—		
1. Operator of lantern	2 2 0	
2. Porter	1 0 0	
3. Tea	2 10 6	
		5 12 6
Care of Stock of Publications, J. Mugford, Annual Fee		1 1 0
Editor's Honorarium		50 0 0
Librarian's Honorarium		5 0 0
Stationery		2 8 6
Postage—		
1. Hon. Secretary	1 3 0	
2. Editor	0 15 0	
3. Librarian	0 1 9	
4. Hon. Treasurer (not charged)	0 0 0	
		1 19 9
Donation towards Memorial Plaque in memory of W. H. Wollaston, F.R.S.		2 2 0
Bank charges, cheque book, and other small items		0 10 4
Balance, December 30, 1933—		
1. At Bankers:		
(*a*) Current Account	16 14 3	
(*b*) Deposit Account	220 0 0	
2. In Office	0 13 1	
		237 7 4
		£667 0 5

Examined and compared with vouchers and found correct.

A. F. HALLIMOND
L. HAWKES } Auditors.

January 8, 1934.

F. N. ASHCROFT, Hon. Treasurer.

BALANCE

Liabilities.	£	s.	d.	£	s.	d.
					December	
To Annual Subscriptions received in advance—						
1. Received in 1932 for 1934	0	14	3			
2. Received in 1933 for 1934	7	10	0			
3. Received in 1933 for 1935	1	1	0			
				9	5	3
Sundry Creditors—						
Messrs. Wightman & Co.				2	14	6
Excess of Assets over Liabilities				1151	12	11
				£1163	12	8

COMPOSITION FEES ACCOUNT

Receipts.	£	s.	d.	£	s.	d.
By Composition Fees received as per last Account	1128	15	0			
Composition Fees received during year	10	10	0			
				1139	5	0
Income—						
Interest on Investments as received—£975 3½ % War Loan 1952, Inscribed Stock				34	2	6
				£1173	7	6

SHEET

30, 1933.

Assets.	£	s.	d.	£	s.	d.
By Balances—						
General Purposes Account:						
1. At Bankers:						
(*a*) Current Account	16	14	3			
(*b*) Deposit Account	220	0	0			
2. In Office	0	13	1			
				237	7	4
Sundry Debtors—						
1. Publishers, (Oxford University Press):						
(*a*) For sales of Publications, April 1–Dec. 30, 1933	25	0	1			
(*b*) For advertisement Fees, April 1–Dec. 30, 1933	17	11	0			
2. For other sales	0	12	0			
				43	3	1
Investments at Broker's Valuation—						
1. £640 3½ % War Loan 1952, Inscribed Stock at 101¼ %	648	0	0			
2. £105 4 % Consolidated Loan 1957, Inscribed Stock at 109¼ % 'ex' div.	114	14	3			
3. £100 4% Funding Loan 1960–90, Inscribed Stock at 112 %	112	0	0			
				874	14	3
Annual Subscriptions in Arrear, estimated to realize				6	6	0
Entrance Fees in Arrear				2	2	0
				£1163	12	8

Note.—The value of the Library, that of the unsold Stock of Publications, and the cash at Bankers and Securities allocated to the Composition Fees Account are not included in the above assets.

January 16, 1934. F. N. ASHCROFT, Hon. Treasurer.

YEAR ENDING DECEMBER 30, 1933.

Payments.	£	s.	d.	£	s.	d.
To Investments as per last Account—						
£975 3½ % War Loan 1952, Inscribed Stock valued by Brokers at £987 3*s.* 9*d.* (101¼ %)	1128	15	0			
Investments made during year	0	0	0			
				1128	15	0
Income transferred to General Purposes Account				34	2	6
At Bankers, Dec. 30, 1933—						
Current Account				10	10	0
				£1173	7	6

Examined and compared with Vouchers and found correct.

A. F. HALLIMOND
L. HAWKES } Auditors.

January 8, 1934. F. N. ASHCROFT, Hon. Treasurer.